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A FEASIBILITY ANALYSIS OF THE

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EMPLOYMENT OF SATELLITE IMAGERY TO MONITOR
AND INSPECT SURFACE MINING OPERATIONS IN
WESTERN KENTUCKY

FINAL REPORT

VOLUME I

(E77-10189) A FEASIBILITY ANALYSIS OF THE
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AND INSPECT SURFACE MINING OPERATIONS IN
WESTERN KENTUCKY, VOLUME 1 Final Report
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The study was initiated by Robert E. Nickel, who was the Principal Investigator from February, 1975 until January, 1976 and William S. Kelly, Project Coordinator from February to August, 1975. These responsibilities, in turn, were assumed by Birney R. Fish in September, 1975 and January, 1976. Claude Downing and Baird Cook has primary responsibility for selecting the study area, for overseeing the ground truth operation, and for validation of parameters used in the model to describe the inspection process.

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EXECUTIVE SUMMARY

Using available NASA technology, many strip mine inspection functions can, in principle, be done by satellite as well or better than by aerial photography or by manned inspection on the ground. The key advantages of environmental surveillance by satellite compared with other methods is that a single, inexpensive (\$200 per image for computer tapes), instantaneous, nearly undistorted image can be obtained up to forty (40) times a year, depending on cloud cover for either the East Kentucky or the West Kentucky coal fields. Furthermore, the labor-intensive functions of photo-interpretation and map making can be done automatically by computer including the print-out of audit data, such as acres disturbed and special maps for field and office use.

Unfortunately, the high resolution equipment needed for thorough environmental monitoring is not yet available on the Landsat series of satellites, even though adequate technology exists and is being used for other applications. This limits the value of Landsat-1 and -2 data to problems such as the percent vegetative cover of areas in excess of about ten (10) acres. Despite the importance of the resolution problem, probably the most negative factor in our attempts to use satellite imagery is the long procedural delay between satellite overpass and user acquisition of data. While NOAA routinely makes weather satellite imagery available to television stations within no more than a few hours of observation, the best we experienced was six (6) weeks for delivery of Landsat data.

While the size of waterway likely to be involved in a transient "water quality" violation is so small as to preclude effective satellite

detection by direct observation, there is NASA technology, not tested in this study, which can be applied. Rapid detection of water quality violations during strip mining can be done by the use of Landsat satellites to relay data telemetered from in situ stream monitors.

It is anticipated that the enhanced resolution of the return beam vidicon sensor (RBV) of Landsat-C, scheduled to be launched late in 1977, will effectively solve the spatial resolution problem relating to re-grading violations, to the detection of mining off of the permitted areas, and to the discovery of unpermitted "wildcat" strip mines. If some administrative means can be effected to make the RBV imagery available through a system similar to that of the NOAA weather data, then Landsat-C and subsequent satellites in the series could provide a valuable and cost-effective means of routine monitoring for violations of surface mine regulations.

I. INTRODUCTION

Coal mining generates costly disruptions to the environment. These costs can extend far beyond the temporal and spatial region in which the mining takes place unless adequate preventive measures are undertaken. Mining laws have been written to require mine operators to undertake such preventive measures. To enforce these laws, inspections are made frequently at those mines which have a permit. (Having no permit is also a violation.) Inspections are also costly. A measure of the effectiveness of an inspection-enforcement process is given by the total social cost of the coal mining violations under the process plus the inspection cost minus any benefit such as fines for violations. A new policy is cost-effective if it reduces the total costs. By careful analysis of inspection policies, an optimal policy can be derived.

The Office of Planning and Research of the Department for Natural Resources and Environmental Protection has undertaken a study to determine the cost effectiveness of employing satellite or aircraft photography together with man "ground truth" inspections for the detection of surface mining violations in western Kentucky. Working as consultants to this project are the firms of MATHEMATICA, Inc., Environmental Research Institute of Michigan (ERIM), and Ford, Bacon & Davis, Inc. MATHEMATICA's task for this project has been to develop violation-inspection-enforcement cost models, estimate the parameters for these models, derive cost estimates for the alternative inspection processes, and determine an optimal cost-effective inspection policy.

There are four general inspection policies to be analyzed. One of these (satellite-air-man) is to use satellite photography followed by low altitude aircraft photography whenever a "detection" is made, which is then followed up by a man inspection if the low altitude photography results in a detection. The other three are satellite-man inspection, air-man inspection, and manned inspection only. Three further policies defined by the same models are given by replacing satellite inspection with high altitude aircraft inspection. Within these policy categories there are several options. For example, aerial photography can be made with a combination of one or more of black and white, color, b&w IR, and color IR. Also the choice of "data sets" from the Landsat satellites is extremely large, depending on the computer decision rules for interpreting the electronic signals.

The effectiveness of satellite and aerial photography depends on the frequency with which the two types of misclassifications occur.

These misclassifications are:

- "detecting" a violation which does not exist
- missing a violation which does exist.

As a preliminary research to this project, Maxim and Cullen [19] of MATHEMATICA developed a model which depends on these misclassification probabilities. Their model uses a single satellite and/or airplane pass under the assumption that N_1 mines out of N have a violation. Their model determines which of s-a-m, s-m, a-m, or man inspections is optimal as a function of N_1 . This paper is included in Appendix A, Volume II of this report. Their paper illustrates the effects of misclassification probabilities

and other major components of the detection process. The final model used in Chapter III is the same as this model except a time dimension has been added to determine the frequency with which a mine should be visited. The optimal policy is a saddle point involving, on the one hand, minimizing the costs of N_1 violations and, on the other hand, minimizing inspection costs. We have also included time delays for violations to "die," time lags.

Because of misclassification probabilities are important in the estimation of costs, an analysis of the effectiveness of satellite and aerial photography depends strongly on the knowledge of the ground truth status of the mines. Ground truth data was also used for another purpose. The computer decision rules for satellite photographic interpretation are more accurate if a sample of ground truth regions, "training sets," are used for classifying the electronic surveillance data into the relevant categories. It is very probably that misclassifications are much higher at any time after the initial "trained" photography because the photographic pixels depend on conditions which fluctuate daily, and to a greater extent, seasonally. ERIM used training sets as one of the options in the computer interpretation of the Landsat data (Appendix C) to generate "recognition" maps of mined areas (Appendix D).

In November of 1975, photographs from Landsat, high altitude aircraft, low altitude aircraft, and from the ground were all taken concurrently (Appendix D). Because of several delays in the development of this data, a meeting in Madisonville, Kentucky to analyze the results could not be held until July, 1976, after the official end of the project. Results of this meeting are summarized in the next section and in the conclusions of this report.

The effectiveness of an inspection-enforcement policy depends on the frequency with which violations occur under the policy. Of the many possible violations, four categories of violations have been used in the model. These are:

- Water quality. Water must be chemically treated before it is drained from the pit in order to reduce its acidity and heavy metals solubility.
- Drainage Control. Diversion ditches must be constructed to divert water from running into the mining area. Sediment ponds must be constructed when mining moves into a new drainage area.
- Grading. Grading must be kept current to within two spoil piles of the mining area.
- Revegetation. During each seeding season, which occurs for two-month intervals twice per year, graded areas must be revegetated.

Kentucky mining regulations applicable to strip mining are given in detail in Chapter II.

There are several approaches to measuring the social costs of violations. One method, commonly used in the past, is to equate social costs with rehabilitation costs. It is now more common to include the cost of rehabilitation as only one component of the cost. The other component is a function of the time during which the environment is

affected. The first component is a terminal cost since once the violation is corrected, it ceases to exist. The second component is an interim cost.

Of the two components, only the interim social cost is used. Annual permit renewal and bond release regulations in Kentucky are such that most grading and revegetation violations do not require rehabilitation (see Chapter IV). Water quality and drainage control violations have social costs proportional to their durations. There is no significant additional fixed cost of rehabilitation. Estimates of these social costs are given in Chapter V.

Fines are benefits or negative costs of an inspection policy. In the past, of the four major violation types, only fines for water quality violations have had any significance. We assume that a violation results in a fine at most once during its interim of existence. Estimates of the average fine and frequency of fines per at least one detection of water quality violation are given in Chapter V.

A good violation model must have at least two frequency parameters to describe the frequency with which they start and the expected duration after they have started. The cost model is very sensitive to these parameters. For examples, a satellite-man inspection policy is ineffective for detecting water quality violations if water quality violations last only three days and there is a two-month lapse between satellite and man inspections. On the other hand, a satellite-man policy is effective for detecting lengthy revegetation violations if there are no misclassifications. In Chapter III the complete cost/benefit model for the inspection policies is developed. This model describes all of the parameters used to define the violation

frequencies, the inspection frequencies, the resulting rate of detections, and the total costs of violations plus inspection minus fines.

Estimates of violation frequencies for the 1971-74 interval are not sufficient because they depend upon the inspection rate; whereas the model parameters for the occurrence of violations are defined independently of the inspection rate. To obtain these parameters, formulae which are developed in Chapter III were used. We first obtain the estimate of violation frequencies for the 1971-74 period and then solve the formulae of Chapter III to estimate those model parameters which give the 1971-74 observed frequencies.

The optimal cost effective policy is determined in this report by two methods:

- Mathematical formulae for the man-only inspection policy
- Computer simulation for the other three options.

The mathematical formulae given in Chapter III are necessary for deriving estimates of the parameters for the computer simulation. They can be used also to derive the optimal man inspection policy in terms of frequency of inspection. This optimal policy is derived in Chapter V.

In Chapter VI we give the estimates of misclassification probabilities resulting from the photointerpretation analysis done at the July, 1976 meeting in Madisonville, Kentucky. These estimates are used in the computer simulation for the costs of satellite and air inspection policies.

In the following section, we summarize the conclusions of our study. Conclusions about optimal inspection policies are covered more extensively in Chapters V, VI, and VII.

Overview of Conclusions

The first major finding with respect to satellite inspection policies that significantly impacts the cost effectiveness of satellite or airplane inspection policies is the estimated average durations, start frequencies, and social costs of the four violation types. Estimates for the 1971-74 period are shown below.

Frequency and Costs of Violations During 1971-74

Violation	Number of Starts Per Permit Per Year	Average Duration in Weeks	Total Social Costs Per Permit Per Year
Grading	1.357	15.7	\$ 525
Revegetation	0.338	20.2	164
Water Quality	0.055	1.0	2,785
Drainage Control	1.208	8.6	1,109

As can be seen from inspection of the above table, sixty-two percent of the total social costs are due to water quality violations. A disappointing result of the study is that, given the dimensions of the water areas on surface mines and the image processing techniques employed by ERIM, water quality violations were undetectable by satellite. A similar situation exists for drainage control and grading violations. Only revegetation violations could be detected with consistency - and, in terms of estimated social costs, these are the least important of the violations.

The second consideration is the relative costs of satellite versus air or man inspection. Our best estimate of the cost of satellite inspection

of the western Kentucky active coal mining area is \$2,000. The cost of airplane inspection of 124 permitted areas is estimated to be \$2,116 and the cost of ground inspection of 124 permitted areas is estimated to be \$3,521.60. The cost estimate for airplane inspection is based on color IR photography. Airplane inspection and satellite inspection are of comparable cost for coverage of the known permit areas for surface mines in western Kentucky.

Satellite photography is less expensive than airplane photography only if the total required area coverage is increased. If the entire active coal mining area in western Kentucky were covered by aerial photography, the cost would be \$6,110 not including photointerpretation. Such coverage might be necessary for the detection of wildcat strip mining (mining without a permit). However, if the airplane photographer were an inspector, photography would be required only when mining was observed. The cost would remain at \$2,116. In any case, the question of whether a search for wildcat strip mining in the future would be beneficial under any assumed inspection costs is moot. (See Chapter VII.)

The future capabilities of satellite may include sharply reduced misclassification probabilities and a short turn-around time for manned inspections. Because of the approximate equivalence of airplane and satellite costs, airplane-man policies and satellite-man policies would be equivalent given similar misclassification probabilities. Thus, the conclusions below for airplane-man policies also apply to satellite policies. (Under no misclassifications, obviously satellite-man is more effective than satellite-air-man).

Airplane-man inspections are more cost effective than ground inspection under the following conditions:

- There is no elapsed time between airplane and ground inspection.
- There are no violation misclassifications under aerial inspection.
- Each ground inspection costs at least \$30.89.

The computer simulation runs assumed that a ground inspection is made after each airplane detection of a violation. In practice, inspection costs could be decreased by having fewer ground inspections. Thus, a permit area having only a revegetation violation would not need frequent ground inspection during the off-seeding season. More than two ground inspections of grading violations during a three-month period is unnecessary.

The optimal ground inspection rate is about once every ten days. The optimal airplane-man inspection rate is about once per week per airplane inspection, with follow-up man inspection within three days. If the only benefits of detecting water quality violations are fines, and if these fines can be made as a result of airplane inspection only, then the time between airplane and man inspections can be decreased.

Because the optimal inspection rate is once per week, and because satellite inspections can be made only about once every thirty days under cloud-free conditions, airplane inspections are better. The high inspection rate is only necessary to detect the short-lived water quality violations.

Stricter enforcement through stiffer penalties is another means of reducing violations. Through higher fines it is possible that water quality

violation frequencies could be reduced to insignificance. In that case lower inspection rates would be optimal. Also, the elapsed time to a follow-up ground inspection would not be critical. Satellite policies would then be cost-effective.

There are additional benefits from using satellite or aerial inspections which are not included in our cost/benefit analysis. Some of these benefits are discussed in Chapter VII.

II. SURFACE MINING LAWS AND THEIR ENFORCEMENT IN WESTERN KENTUCKY

1. An Introduction to the Industry

There are several distinct types of coal surface mining: open pit, area stripping, contour stripping, and auger mining. Each has a different effect on the land. Surface mining refers to those methods of mining in which overburden is removed in order to expose the coal deposit. Area strip mining, or simply strip mining, is surface mining where the overburden is removed in narrow, consecutive strips, producing a surface of ridges called spoil piles.

Area strip mining is used on gently rolling to relatively flat terrain where the coal bed is relatively flat. There are at least two techniques for removing the overburden. The full cut technique removes the entire overburden with each pass of the equipment. The bench technique is used in areas of thick overburden. This technique uses two passes of equipment to remove the overburden. Under either technique, except for the first cut, the overburden of each succeeding cut is placed in the previous cut. Currently, few operations remove the overburden by strata or keep the topsoil for future rehabilitation use.

In terms of tons of output, western Kentucky ranks approximately sixth in coal production in the nation. In 1974, 51.8 million tons of coal were mined in the area: approximately nine percent of the U.S. total and 38 percent of the Kentucky total. Research at the University of Kentucky [1], shows that the coal production for both underground and surface mining has been growing over the past eight years. Total production has increased from 46.4 million tons in 1967 to 51.8 million tons in 1974.

Mining causes a disturbance of land and water in complex ways. Within the base boundary, it affects the geology, topography, and physical and chemical characteristics of the land. The cutting of impervious material has a profound effect on the hydrologic characteristics of the land. Archeological, historical, and cultural values of the land plus other special, unique features are affected. But the major ecological effects of coal mining do not stop at the base boundary. Acid water runoff, sedimentation, and the alteration of natural drainage affect the water systems for miles around. Plant and wildlife as well as aesthetic considerations must also be included in the social costs of mining.

The Commonwealth of Kentucky has enacted legislation, Chapter 350 of the Kentucky Revised Statutes (KRS 350) to control the extent of environmental impacts caused by coal mining. Regulations derived from KRS 350 are published under Title 402 of the Kentucky Administrative Regulations. In the next section we outline some of those regulations.

2. Strip Mining Regulations

The following regulation 402 KRA 1:060 relates to KRS 350 is in effect:

Sediment Control Planning

Section 1. (1) Prior to the issuance of a permit by the Division of Reclamation for surface mining all the following conditions must be met:

- (a) A drainage, erosion, and sediment control plan for the area to be permitted must be prepared by a registered professional engineer or the local conservation district and submitted to the division for approval.

(b) Following approval by the division, the operator shall construct water retarding structures, sediment dams, or sediment ponds in those drainage areas to be immediately affected by the operation.

(c) Said construction must be certified by a registered professional engineer or the local conservation district.

(2) Construction and certification shall be kept current after the issuance of the surface mining permit until completion of the mining operation.

(3) No surface mine sediment dam shall exceed twenty (20) feet vertical distance between the lowest point of the valley floor and the crest of the emergency spillway.

(4) Following approval of the vegetative cover on the surface mining operation, the division may require removal, backfilling and grading of water retarding structures, sediment dams, and sediment ponds constructed by the operator under this regulation. Removal shall consist of complete draining, removal of collected silt and the constructed embankment, spreading the material in a location away from streams and seeding the area involved.

(5) All areas disturbed in the construction of sediment dams, basins or water retarding structures shall be revegetated.

(6) The director may, with approval of the secretary of the department, after written request by the operator and justification therefore, provide for exceptions to this regulation consistent with the requirements of KRS Chapter 350.

The following regulation 402 KAR 1:055 relates to KRS 350 is in effect.

Water Quality Criteria

Section 2. In order to establish and maintain an effective program for assuring high quality water in the Commonwealth, operators shall comply with the following requirements:

(1) Treatment facilities of sufficient size and number consisting of, but not limited to, collection basins, water retarding structures and silt dams shall be constructed prior to the stripping operation for maintaining a quality of water to specifications in subsection (3) of this section. The location of all sediment control facilities shall be indicated on the permit map(s) prior to issuance of the permit.

(2) All treatment facilities shall be kept in proper working order to maintain those specification in subsection (3) of this section, until the operator can demonstrate that these specifications can be met without such treatment facilities. Records of treatment shall be maintained by the operator on forms furnished by the division.

(3) The operator shall prevent discharge of drainage into the waters of the Commonwealth from the area of land affected, the pH of which is less than 6.0 or greater than 9.0 or which contains a concentration of iron in excess of seven (7) milligrams per liter (mg/l). The total alkalinity of the discharge must exceed the total acidity. The discharge shall contain no settleable matter, nor shall it contain suspended matter in excess of 150 Jackson Turbidity units, except during a precipitation event, which the operator must show to have occurred, in which case 1,000 Jackson Turbidity units may not be exceeded. Suspended matter in parts per million (ppm) may not exceed the Jackson Turbidity units multiplied by 2.20. Sampling

and analyses are to be defined and performed to "Standard Methods for the Examination of Water and Wastewater", Thirteenth Edition, unless otherwise specified in writing by the division.

Under a study sponsored by the U. S. Environmental Protection Agency, Hittman Associates, Inc. (2) has conducted an in-field evaluation of the effectiveness of silt structures in reducing the suspended solids in the runoff from surface mining activities.

Field sampling programs were conducted by Hittman Associates at six sedimentation ponds. The average suspended particle solids (mg/l) were measured at inflow and outflow points under baseline and rainfall conditions. The removal efficiency was made by comparing effluent with influent. The results varied from a low efficiency of 36.4% to a high efficiency of 92.8%. Hittman Associates were able to show that in cases of low efficiency, the sedimentation ponds were poorly constructed or maintained. Causes of poor water quality were unvegetated steep banks leading to the pond, insufficient width, length, or depth, and poor inflow drainage systems. They conclude that silt structures are adequate if proper construction and maintenance procedures are followed.

Water Quality - Chemical

Low pH water is produced by coal mining in areas containing acid producing overburden. At low pH levels, heavy metals such as iron, manganese, copper and zinc are more soluble and further pollute the water. Water of this type supports only limited water flora, such as acid-tolerant molds and algae. The water will not support fish life, destroys and corrodes

metal piers, culverts, barges, etc., increases the cost of water treatment for power plants and municipal water supplies, and leaves the water unacceptable for recreational use.

Control of acid mine drainage is done by using diversion ditches and by sealing, impoundment or chemical treatment to neutralize acidity. When water is to be drained from a pit or a pond it should be chemically treated. The following regulations apply to acid mine drainage.

Acid Mine Drainage (Grading)

Section 4. When an abandoned underground mine or acid mine drainage is encountered in the operation, it shall be reported to the Division and handled in accordance with 402 KAR 1:055.

Acid Materials (Grading)

Section 5. All acid-producing or toxic materials (including by way of illustration, but not limited to, rider, rooster, blossom, honey, culm or other sulphur-bearing or aluminum-bearing substances) disturbed shall be buried under at least four (4) feet of clean overburden.

Intermittent Streams

Intermittent streams in the area of land affected shall be kept free of spoil material for a minimum distance of fifty (50) feet on each side of the channel. The division may grant permission to operate within these limits provided all excavated materials are hauled beyond the fifty (50) foot limit and proper sized cross drains are placed in the stream for crossing purposes.

Drainage

No drainage shall be discharged into underground mine workings. When an underground mine or mine drainage is encountered, the operator shall report this occurrence to the division and bring any discharge into compliance with subsection (3) of this section immediately. Plans must be submitted within five (5) days for permanent control. Upon approval by the division, the operator shall comply to the plans within thirty (30) days.

Sudden release of large volumes of water onto outer slopes of spoil banks is prohibited.

All drainage originating on the area of land affected must meet the specifications in subsection (3) of this section or exit through treatment facilities in accordance with subsection (1) of this section.

The following regulation 402 KAR 1:030 relates to KRS Chapter 350 is in effect.

Backfilling and Grading

Reclamation should follow closely behind the mining operation. The bare spoil and pit should be reclaimed as fast as possible because the freshly moved material is easier to grade, handle and plant than older compact material. Bare spoils and pits are more susceptible to acid formation and erosion. Backfilling and grading should be kept current with the strip mining operation. The Commonwealth of Kentucky has regulations which require current grading. These are listed below.

Current Grading

Section 6. In order to be considered current, grading and backfilling shall meet the following requirements:

- (1) On lands where the method of operation does not produce a bench (area strip mining), the grading and backfilling shall not be more than two spoil ridges behind the pit being worked, the spoil from this pit being considered the first ridge. All backfilling and grading shall be completed within ninety (90) days after the completion or suspension of an operation. Modifications to these requirements may be made by the Division in connection with the backfilling of the final pit.
- (2) On lands where the method of operation produces a bench (contour strip mining, auger mining and highwall mining), all coal must be picked up within thirty (30) days following removal of the overburden and the following requirements must be met:
 - (a) If the operation includes only stripping (no augering or highwall mining), the grading and backfilling shall follow the coal removal by not more than fifteen (15) days, but in no instance shall an area be left ungraded more than 1,000 feet behind the removal of the coal.
 - (b) If the operation includes stripping and augering, the augering shall follow the stripping by not more than thirty (30) days and the grading and backfilling shall follow the augering by not more than fifteen (15) days, but in no instance shall an area be left ungraded more than 1,000 feet behind the augering.
 - (c) If the operation includes stripping and highwall mining, the highwall mining shall follow the stripping within

sixty (60) days, and the grading and backfilling shall follow the highwall mining by not more than fifteen (15) days, but in no instance shall an area be left ungraded more than 1,000 feet behind the highwall mining.

(d) If the operation includes only augering or highwall mining, the grading and backfilling shall follow the augering or highwall mining by not more than fifteen (15) days, but in no instance shall an area be left ungraded more than 1,000 feet behind the augering and highwall mining.

(e) Modifications to these requirements may be made by the Division.

(3) If heavy rains or wet conditions make grading impracticable, the period of time required to be current shall equal the number of production days lost due to these heavy rains and wet conditions.

Backfilling and Grading

Section 2. Backfilling and grading as required by KRS 350.093 shall be performed as follows:

(1) On lands where the method of operation does not produce a bench (area strip mining):

(a) Complete backfilling shall be required, beginning at or beyond the top of the highwall and sloped to the toe of the spoil bank at a maximum angle not to exceed the approximate original contour of the land with no depressions to accumulate water, and all highwalls and spoil peaks shall be eliminated.

- (b) Water diversion ditches or terraces shall be constructed in the final grading to control water runoff and erosion on long uninterrupted slopes and to remove surface water runoff to a safe outlet. For the purpose of this regulation, a diversion ditch shall be a channel constructed on a continuous grade of one to two percent (1%-2%) across the slope with a supporting ridge on the lower side and the entire ditch seeded to an adaptable grass or grass-legume mixture. The depth and width of the diversion ditch may vary depending on the length and degree of slope.
- (c) Lands shall be deemed to have been completely backfilled and graded to their approximate original contour when:
1. The contour of the land conforms approximately to the contour of the original ground, but the final surface of the restored area need not necessarily have the exact elevations of the original ground surface. However, where a flat surface or a surface with less slope than the original ground surface is desired, such surface shall be deemed to comply with backfilling and grading to the approximate original contour.
 2. Spoil abutting onto unstripped land has been graded so as to blend into the adjoining unstripped lands.
In order to prevent excessive disturbance of the adjoining unstripped lands through the placing of

spoil onto already vegetated areas, spoil will be considered as blending into the unstripped lands if the angle between the spoil and the unstripped land is twelve degrees (12°) or less.

Section 3. (1) Where a water impoundment is desired under the provisions of KRS 350.093(3), such impoundment shall be submitted for approval to the Division of Reclamation and provide the following minimum standards:

- (a) No leakage into and/or from old underground works.
- (b) The surface area when filled shall not be smaller than one-half acre.
- (c) Seventy-five percent (75%) of the proposed impoundment shall be at least six (6) feet deep.
- (d) The ratio of the proposed impoundment surface area to the watershed drainage area shall not be less than 1:5.
- (e) If the watershed drainage area supplying the proposed impoundment is composed of 50% spoil area, then the impoundment surface area ratio to the watershed drainage shall increase from 1:5 to 1:10.
- (f) No highwall shall exceed twenty-five (25) feet measured from the permanent pool elevation. All shale and/or earth above the solid rock line shall be reduced to a slope not to exceed twenty-five degrees (25°).
- (g) Pool widths at normal pool elevation when measured at ninety degrees (90°) to the highwall face shall in all cases be equal to and/or greater than two (2) times the combined heights of the highwalls at that given point.

- (h) All grading done on highwalls above the twenty-five (25) feet maximum height set out in Section 6 of this regulation shall result in no slopes greater than twenty-five degrees (25°).
- (i) The grading of spoil areas surrounding the proposed impoundment, shall be to a maximum slope of twelve degrees (12°). This slope shall continue into the proposed impoundment area to a point where the slope blends into the bottom of the pit, and/or the depth of the water becomes six feet (6') whichever comes first.
- (j) In areas where the approved highwall is closer than two hundred (200) feet to a property line, shops, rental properties, public roads, or any other areas where the public might be endangered, then a suitable fence shall be constructed along the top of the highwall.
- (k) When the natural relief system has been obstructed by an artificial embankment in order to aid in the creation of an impoundment, the embankment section shall be approved by the Division of Water Resources and a conservation permit issued (in accordance with KRS 151.250) before Reclamation approval will be considered.
- (l) In areas where highwalls are reduced and the act of reduction causes a separation in the excavated pit resulting in more than one impoundment, then these reduced highwalls and their resulting outslopes may be reduced to a maximum twenty degrees (20°).

- (m) Requests for all proposed impoundments shall be presented in writing to the Division of Reclamation prior to the beginning of the last cut.
 - (n) The written request shall be accompanied by maps compiled by company engineers showing drainage area in acres, percentage of the drainage area classified as reclaimed spoil, points of minimum and maximum width, surface area of proposed impoundment, acre feet storage, and arguments for the feasibility of requested impoundment.
 - (o) All impoundments (if approved) shall be on a tentative basis of not less than one year nor more than two years. If at the end of the tentative approval period the impoundment should fail to measure up to the laws, rules, and regulations of the Division of Reclamation, then the entire area involved shall be totally completely graded in accordance with the laws, rules and regulations of the Division of Reclamation. The operator shall have 45 days to submit a complete, detailed plan, indicating a completion date for all grading of the entire area.
- (2) All spoil piles adjoining access roads to water impoundment shall be reduced to the approximate original contour of the surrounding area. Adequate drainage shall be provided and measures taken to prevent erosion of the slope, including but not limited to, terracing, vegetation, etc. The road bed must be adequately drained and culverts provided so as to prevent it from being eroded.

- (3) The area above the highwall on any water impoundment shall be planted with trees in order to provide a protective barrier and screen. The trees to be planted are as follows:
- (a) Three (3) rows of Locusts - 4' x 4' spacing, adjacent to the highwall.
 - (b) Three (3) rows of Conifers - 4' x 4' spacing, in front of the Locusts.
 - (c) The above trees are to be planted in such a way that they will not be carried over the highwall by erosion but not so far back that they will not provide a protective barrier and screen for the top of the highwall. All such planting will be subject to the approval of the area supervisor.

The following regulation 402 KAR 1:040 relates to KRS Chapter 350 is in effect.

Revegetation requirements

Section 1. The operator shall submit with the application for a permit a proposed revegetation plan compatible with these regulations. A chemical analysis to determine potential acidity of the potential overburdens may be required if deemed necessary by the Division of Reclamation. No portion of the bond shall be released until the requirements of subsections (1) to (8) of this section have been met and a detailed planting report submitted to the division.

- (1) Revegetation shall include seeding and establishment of permanent grasses and legumes as approved by the Division of

Reclamation and at seeding rates as recommended by the division. Temporary or quick cover species may be required in combination with the permanent species on some areas to control erosion. The seeding rates of these temporary species should not exceed the rates approved by the division.

In the Western Kentucky coal field seeding shall be done on all spoil or other disturbed areas, including access roads within (45) days after grading is finished. This requirement is suspended for the period from October 15th through February 15th and from May 15th through August 1st. Some method of erosion control may be required when an area is ready to seed between seeding periods. Warm season grasses may be seeded from April 15th to June 15th.

- (2) A chemical analysis of the spoil material shall be made to determine the lime and fertilizer requirements. A chemical analysis of a minimum of one (1) composite spoil sample per ten (10) acres of disturbed surface shall be required. A composite sample shall consist of at least (10) thoroughly mixed sub-samples from the area. More samples may be required depending on the variability of the spoil and the size of the permit. The operator will be held responsible for meeting the above requirements. The chemical analysis must be done by laboratories operated under the supervision of the Kentucky Agriculture Experiment Station or other laboratories approved by the Division of Reclamation. Sufficient agricultural limestone or an approved substitute shall be applied

and incorporated into spoil to raise the water pH to a minimum of 5.5 or 6.4 on those areas approved for grasses and legumes only. All limestone used shall be purchased from agricultural limestone dealers licensed by the State Department of Agriculture. The SMP buffer pH method shall be used to determine the lime requirement if the water pH is below 6.0. The potential acidity tests or total sulfur analysis shall be required on areas where acid problems are suspected to more accurately determine the lime requirement. Where lime is required, it shall be incorporated into the spoil to a depth of six (6) inches. No portion of the bond shall be released until a stable water pH of at least 5.5 or 6.0 for grasses and legumes has been attained on at least eighty (80) percent of the area.

- (3) Minimum fertilizer requirements for revegetation shall be 100 pounds of available P_2O_5 per acre and sixty (60) pounds of available nitrogen per acre. The nitrogen application may be split, with one-half ($1/2$) put on at time of seeding and one-half ($1/2$) during first part of the next growing season. In those areas where grasses and legumes are approved, the operator shall apply a minimum of 150 pounds of P_2O_5 per acre and a minimum of sixty (60) pounds of K_2O per acre in addition to the sixty (60) pounds of nitrogen. The division may approve lesser amounts of fertilizer if approved spoil test indicate lesser amounts are needed for satisfactory revegetation.
- (4) Mulch shall be required on all disturbed areas where the slope exceeds fifteen (15) degrees, on disturbed areas with a buffer

pH below 5.0 prior to liming, on all areas where seedbed preparation is impossible and on all areas that are seeded to predominantly cool season species from June 1st to August 1st. Mulch may be required by the Division of Reclamation on other problem areas. A material to hold the mulch in place may be required. The acceptable mulching materials and minimum rates are listed below:

<u>Material</u>	<u>Rate/Acre</u>
Straw or hay	1 1/2 tons
Wood Bark	45 cubic yards
Wood Fiber	1,500 pounds

Other mulching materials may be approved if shown to be satisfactory.

- (5) Trees shall be planted at no less than 800 seedlings per acre on all disturbed areas except benches formed by contour mining, level areas created by mountaintop removal, and areas in Western Kentucky that are approved for grasses and legumes only. The landowner must indicate his preference for grasses and legumes before an area will be considered for approval without the establishment of trees. Kentucky grown nursery tree seedlings are encouraged but seedlings acclimatized to Kentucky conditions may be used. Direct seeding of Black Locust trees at the rate of two (2) pounds per acre may be a satisfactory method of establishing trees. (See Section 5.)
- (6) Shrubs for wildlife may be planted in lieu of tree seedlings and may be planted on any part of the mined area and may include border plantings, clump plantings, and intervening strips.

- (7) All legume seed, except Black Locust, shall be inoculated with the proper strain of bacteria immediately prior to seeding. The inoculation rate shall be increased four (4) times if a hydroseeder is used.
- (8) A seedbed shall be prepared by scarifying the spoil immediately prior to seeding except where the seeding is done on freshly graded material or on spoil loosened by frost action.

Section 2. At least twenty-four (24) hours prior to commencing any re-vegetation activity, the operator may be required to notify the area supervisor for the division and have invoices available for inspection as proof of purchase for seed, seedlings, lime, fertilizer, mulch and spoil test report(s).

Section 3. Roads shall be seeded to legumes and permanent grasses. This may be modified if, in the opinion of the division, the roadway will not contribute off-site damage to the public or adjacent property owners.

Section 4. When seeding or planting is completed, the operator shall file a detailed planting report with the exact amounts of lime, fertilizer, seed and mulch within two (2) weeks with the Division of Reclamation on a form furnished by the division.

Section 5. Standards for permanent vegetation. Prior to complete bond release there shall be established at least a seventy (70) percent ground cover per acre of permanent vegetation on all surface mined areas and at least eighty (80) percent ground cover per acre of permanent vegetation on those surface mined areas which were approved for grasses and legumes only. The permanent vegetation shall consist of both permanent grasses and legumes which are recommended by the Division of Reclamation.

- (1) Standards for Woody Plants: Prior to complete bond release there shall be 600 or more living woody plants per acre, including volunteers, with distribution of stems fairly uniform on all areas except those mentioned in Section 1 (5) of this regulation.
- (2) Inspection will be made by the division at the end of the first and second growing season for purposes of determining vegetation bond release. If the revegetation effort is unsatisfactory, a new plan shall be required to include rates of mulch, seed, fertilizer and lime based on new spoil tests. This revegetation plan shall be submitted to and carried out with the direction of the division. In order for vegetation to be considered current, it shall be satisfactory for bond release by the end of the second growing season. If vegetation is not current, the permitted area shall be subject to bond forfeiture and additional permits shall be denied the operator responsible for such areas until the operator has complied with the remedial measures set forth by the division.

Section 6. The Director of the Division of Reclamation may, with approval of the secretary of the department, after written request and justification therefor by the operator, provide for exceptions to this regulation consistent with the requirements of KRS Chapter 350.

Method of Operation (Wildcatting)

Each mining operator is required to submit plans for the method of operation. If this plan is approved and he posts an appropriate bond, he is

granted an annual permit for the number of acres which he plans to mine during the year within the area covered by the approved plan.

A method of operation violation is all encompassing since it includes any violation of the regulations as well as any method of mining operation which is not according to the approved plan. Most of these violations fall under a specific heading such as revegetation, grading, silt structure, access road, etc. A unique category distinct from the other categories is mining without a permit. A mine operator may be doing a satisfactory job in terms of environmental considerations and still be in violation if he is mining either outside of his permit or without a permit. These violations occur in one of the three following ways:

- mining method - of the miner augers into the highwall when his plan calls for strip mining he is in violation
- mining off the permit area - a miner may have a permit for one area but mine in an area for which he has no permit
- mining with not permit - this is known as "wildcatting".

The following regulation 402 KAR 1:045 relates to KRS Chapter 350 is in effect.

Advance Planning of Contiguous Surface Mining Operations

Section 1. An operator may submit plans for the method of operation plans for grading and backfilling (including water impoundments) and reclamation plans covering contiguous mining areas which may contain more acres than will be mined within one (1) year. The requirements for such pre-planning (herein called "area plans") shall be the same as those for plans for annual permits.

Section 2. If the Division of Reclamation approves an area plan and the approved plan remains consistent with the requirements and purposes of KRS Chapter 350 and regulations adopted pursuant thereto, the operator shall, without submitting additional plans for the method of operation, backfilling and grading, and reclamation, be granted an annual permit for the number of acres which he plans to mine during the year within the area covered by said area plan.

Section 3. If the Division of Reclamation approves an area plan, the operator shall be obligated to conduct its method of operation, grading and backfilling, and reclamation in accordance with said area plan which may be modified providing the modified plan is consistent with the requirements and purposes of KRS Chapter 350 and regulations relating thereto, with the approval of the division.

The following regulation 402 KAR 1:035 related to KRS Chapter 350 is in effect.

Permit and Reclamation Plan

Section 1. Permits shall be issued pursuant to KRS 350.060 only on the condition that the reclamation plan approved pursuant to KRS 350.090 can be carried out. When conditions develop in the operation which show that an approved reclamation plan cannot be carried out as originally proposed or that additional measures must be taken to eliminate damage to the public and adjacent property owners from soil erosion, water pollution and hazards dangerous to life and property, the Division of Reclamation shall order, in writing, such action or inaction as will cause the operation to be in compliance with the requirements of KRS Chapter 350 and the regulations of the

department. The order shall set forth the reasons for which the original plan cannot be carried out and shall be served on the operator by registered mail.

Section 2. If the operator does not agree to the division's order he may, by filing written notice within twenty (20) days after the date of the order of the division, request a hearing in accordance with the provisions of KRS 350.090 and 224.083. The hearing shall be held within twenty (20) days after the request in Frankfort or at such other place as the Division orders, upon reasonable written notice to the operator. The final order of the division shall be issued within twenty (20) days subsequent to the hearing.

Section 3. The hearing provided for in Section 2 of the regulation shall not suspend the order of the division under Section 1 unless so ordered by the Division.

The following regulation 402 KAR 1:025 relates to KRS Chapter 350 is in effect.

Access Road

Coal haul and mine access roads can be a major source of sediment and poor drainage. Upon completion, haul roads are usually abandoned. Area mining, which is practiced in relatively flat terrain, presents fewer haul road related environmental problems than other types of mining. These roads must be well engineered because of the heavy equipment using them.

The Commonwealth of Kentucky requires bonds on coal haul roads which are not released until either the road is turned over to another party, with adequate drainage, or the road is abandoned, with adequate drainage and vegetative cover.

Blasting

In many cases, houses and other buildings are located on properties next to mining operations. Blasting causes air vibrations and pressures which at the least create intolerably noisy, if not, unsafe conditions. Structures are weakened by repeated vibrations from nearby quarry blasting. Blasting may cause serious atmospheric pollution when temperature inversions exist.

III. COST/BENEFIT MODEL

1. Introduction

In this chapter we develop a violation-inspection-enforcement model. This model is an extended and modified version of a preliminary model given in Appendix A. The principal modification we make in the model is the inclusion of a time factor for the violation and inspection process. From the final model, the optimal frequency of inspections at a mine can be determined as a function of parameters defining the frequency of violations under the inspection process. There are several measures of the frequency of a violation:

- average fraction N_1/N of mines which have a violation at any time
- average number of times that a violation begins at a mine during a year
- average duration of a violation once it has begun
- average duration of a violation after it has been detected.

If a violation had a duration of one unit of time, and if there were no time lag between a satellite pass and any follow-up air or ground inspection, the model given in the appendix could be used. However, time is an important element in the model for reasons such as the following:

a. Lapse between satellite pass and detection

By the time a man has inspected a mine, the violations first "seen" by a satellite inspection may have changed. This results in a decrease in fines. Also, between a satellite pass and photointerpretation, a ground

inspection may have been made as a result of a previous pass, thus voiding the need for a new inspection.

b. Social costs

We have defined social costs to be the costs per week per violation. Thus, the longer the period of time between detection and correction, the more the social costs.

c. Frequency of violations

The frequency of a violation type at a mine is the average number of mines for which the violation exists. If this is f , then the expected number of mines having this violation on a given day is:

$$N_1 = fN .$$

Since a good inspection policy curtails the average length of violation, f is a function of the inspection policy. Thus, N_1 itself is a function of the inspection policy and cannot be assumed to be fixed when comparing various strategies.

d. Multiple inspections

Although misclassifications occur, a violation missed during one satellite pass may be detected at a later pass. This assumes that detection probabilities of violations increase the longer they persist. This assumption is reasonable since the persistent violations tend to grow in size (revegetation and grading).

e. Multiple violations

When ground inspections are made, all violations are assumed to be detected at that time. This is not the case for satellite and air inspection.

Violations such as grading and revegetation are misclassified less frequently than other violations. This selectivity changes the characteristics of detected and nondetected violations. For this reason, violations cannot be simply pooled into one single category - the category of "at least one violation" has different characteristics depending on whether it is "detected" or "undetected."

The two costs of a violation which persist during a period of time are the social costs while the violation exists and the terminal costs of rehabilitation or fines. Under the present Commonwealth of Kentucky regulations and enforcement, the social costs are the most important factor (for those mines which have a permit; wildcat mining will be discussed later). Permits are renewed, or bonds are released, on an annual basis. Decisions for permit renewals and bond releases are not made unless the mined area conforms to the statutes of rehabilitation plus other unique requirements specified in the approved method of operation plan. Thus, within an approximate time of one year, all violations within the mining areas are corrected by the mine operators - or bonds are forfeited. This method of control over mine operators assures that the Commonwealth has to pay at most a minimal amount for uncorrected violations.

The positive benefits - or negative cost - entering into the total costs, is the amount of fines collected from detections. During the past few years, this benefit has been negligible relative to the social costs. We do, however, include fines in our cost/benefit model.

Thus, the most significant factor in measuring the effectiveness of an inspection process is not the number of times a violation is detected,

but the amount which the average duration of a violation is reduced by the process.

Every model necessarily is limited in the accuracy with which it portrays real world conditions. Some characteristics which exist but are ignored due to complexity are:

- We assume a single detection of a violation has the same effect on the length of a violation as two or more detections. In practice, multiple detections lead to stiffer enforcement - ultimately leading to fines for non-compliance and/or court-ordered suspension of mining. We do, however, accumulate average fines with each detection.
- The frequency with which violations begin, and the average length of violations, may be voluntarily decreased by a mining operator if he has knowledge that the inspection process has improved and the penalties of detection are sufficiently severe. We have not included this possibility in the model.
- Obviously, the values of parameters in the model are not exact. Nor are assumptions such as independence of detections on different days correct. A violation missed on a clear day has an increased probability of being missed again if it does not grow in magnitude.

Two methods of analysis are used in this report. First, for the ground inspection only policy, exact mathematical formulae are developed using the well-known theory of Markov chains. These formulae are necessary for developing estimates of the average length and frequency of each of the violation types. These formulae also can be used to derive total cost estimates under varying ground inspection rates. From these costs, optional ground inspection rates can be determined.

Items (a) through (e) indicate the complexity of the model which defines a combination of satellite, air, and man inspection policies. Because of lag times between initial inspection and follow-up inspection, an "event" at time t defining the state of violations and detections at a permit area, depends in a complicated manner on all of the events which have occurred during a lag time. For example, a manned inspection may have already been made which voids the need for an additional one. Cloud-cover on the previous satellite pass may require an inspection at the next pass. A violation may end during a lag time. While exact formulae for violation costs, inspection costs, and fines are mathematically intractable, a computer algorithm for defining a simulation of these combined inspection policies is not difficult to develop. Thus, our second method of analysis is computer simulation. Simulations are conducted over a sufficiently long period of time to give accurate cost estimates for each policy.

The events in the computer simulations are defined by a random number subroutine. The computer program was developed in such a manner that the same identical violations were generated with each simulation. (Thus, they are random only during the first simulation.) By this method, each simulated inspection policy is matched against the

same violations. This offers an accurate cost/effectiveness comparison of policies.

All of the combinations s-a-m, s-m, a-m, and m are simulated by the same computer program. The parameters for the inspection policy are defined by

s = elapsed time between satellite inspections
or s = 0 if no satellite inspection
a = elapsed time between satellite detections and airplane inspection
or a = elapsed time between airplane inspections (s=0)
or a = 0 if no airplane inspection
and m = elapsed time from either satellite to man or airplane to man
or m = elapsed time between manned inspections (a=0, s=0).

Technically, when s=0 and a=0, the resulting manned only inspection costs should be equal to those defined by the mathematical formulae. This is indeed the case when simulations are made at daily units of times. To economize, computer simulations were made on weekly and 3.5-day units of time. As explained in more detail in Chapter VII, this longer unit of time results in different fine rates, social costs, and detections of the short-lived water quality violations. Comparisons of the satellite and airplane policies are therefore made only with computer simulated ground inspection policies.

The computer simulation program performs the following in order:

- For each week of the simulation, violations v_{1i} ($i = 1, 2, \dots, n$) begin with probability p_i or, if already begun, end with probability $1 - r_{1i}$.

- Every s days the weather is checked. If $s > 0$ and the weather is clear, a determination is made about whether or not a satellite detects a violation at the mine.
- If $s = 0$, or if a satellite detection has been made, after a lag of d days a determination is made if an airplane detects the violation.
- After a lag of m days, a man inspection is made if called for by a satellite or air detection.
- A second set of "true" violations is generated. The true violations V_i equal the original violations V_{1i} with the exception that a man detection implies the violation v_i ends with probability $1 - r_i$. The true violations always begin at the same time as the original violations.
- Social costs, fines, and inspection costs are accumulated and printed out.

As can be seen, the above simulation accounts for each of the points made earlier about time lags and violation duration curtailments. Details of the simulation program and flowcharts are given in Section 3. Theoretical formulae must be derived for estimating the violation probabilities in a meaningful way from historical inspection data. These derivations are given in Section 2.

2. Violation Model

a. Mathematical formulae

In this section we develop mathematical formulae to define the frequencies which which violation occur under different inspection frequencies and strategies. Let $V_1, V_2, \dots, V_n$ represent the n possible violation types which may

exist at a mine. To denote presence or absence of violations at any time, we use indicator variables $v_1, v_2, \dots, v_n$ defined by

$$v_i = \begin{cases} 1 & \text{if } V_i \text{ is present under the inspection process} \\ 0 & \text{if } V_i \text{ is absent under the inspection process.} \end{cases}$$

The length of a run of $v_i = 1$ is the length of time that a particular violation incident, V_i lasts. The number of runs of $v_i = 1$ is the frequency with which a violation V_i begins. For example, the string of values 0111110110 during a period of ten weeks gives two runs, whose average duration is 3.5 weeks. At a randomly selected time, the probability the violation exists is 0.7. If a detection is made, the initial string may be modified to 0111000110. In this case, the average duration is decreased to 2.5 weeks, the frequency of occurrence is decreased to 0.5, but the number of runs is not changed.

Because a string of runs is dependent on the inspection system, we use a second indicator function v_{1i} to denote violations when no inspection is made.

Under manned inspection, the average duration of a violation can be expressed as a function of the frequency with which inspections are made. However, when multiple violations are assumed under a more complex system of satellite-airplane-man inspection, the formulae for the average durations are excessively complicated. We will, however, derive formulae for manned inspection in this section. We will use these formulae to derive estimates of the violation frequencies and lengths of runs from an analysis of inspection data for 1971 - 1974.

Define the following:

$$P_{1i} = \begin{aligned} &\text{probability of an occurrence of } v_i \text{ at time } t \text{ given} \\ &\text{no occurrence of } v_i \text{ at time } t - 1. \end{aligned}$$

- r_{1i} = probability of an occurrence of v_i at time t
 given an occurrence of v_i at time $t - 1$
 f_{1i} = probability of an occurrence of v_i at time t
 s_i = probability a run of v_i begins at time t
 L_{1i} = average length of a run of v_i .

When ground inspections are made at a mine, all of the variables except s_i are changed. Denote the new variables by p_i , r_i , f_i , s_i , and L_i .

Also, define the following:

- p_D = probability a mine is inspected during any given week
 r_{2i} = probability of an occurrence of v_i at time t given
 an occurrence of v_i at time $t - 1$ and a detection
 of v_i during this run.

The following relations hold:

$$\begin{aligned}
 L_{1i} &= (1 - r_{1i}) (1 + 2 \cdot r_{1i} + 3 \cdot r_{1i}^2 + \dots) \\
 &= \frac{1}{1 - r_{1i}}
 \end{aligned} \tag{1}$$

and

$$L_{2i} = \frac{1}{1 - r_{2i}} \tag{2}$$

where L_{2i} is the average duration of a violation after a detection is made. Thus, r_{1i} and r_{2i} are known when these average durations are known.

The average duration of a violation under an inspection process is an average of the durations of undetected and detected violations. This can be derived from a recurrence formula, .

$$L_i = \frac{p_D}{1 - r_{2i}} + (1 - p_D) ((1 - r_{1i}) + (L_i + 1) r_{1i})$$

$$\text{or } L_i = \frac{1 - r_{2i} + r_{2i} p_D}{(1 - r_{1i} + r_{1i} p_D)(1 - r_{2i})} \quad (3)$$

Thus, L_i can be estimated from L_{1i} , L_{2i} , and p_D . An estimation of the frequency of occurrences of violations v_i under ground inspections, f_i , is simply the ratio of detections of v_i to the number of inspections. This estimate assumes that the selection of mines to be inspected is equivalent to random sampling. The value of r_i is estimated from L_i by

$$L_i = \frac{1}{1 - r_i} \quad \text{or} \quad r_i = 1 - \frac{1}{L_i} . \quad (4)$$

Now, f_i and r_i are related to p_i by the equation

$$f_i r_i + (1 - f_i) p_i = f_i .$$

Thus, p_i is estimated by

$$p_i = \frac{f_i (1 - r_i)}{1 - f_i} . \quad (5)$$

The start frequency s_i is given by

$$s_i = (1 - f_i) p_i .$$

Since s_i is assumed to be independent of the detection system, s_i is also given by

$$s_i = (1 - f_{1i}) p_{1i} . \quad (6)$$

It can be shown that the above equations also give

$$f_i = L_i s_i \quad (7)$$

and

$$f_{li} = L_{li} s_i \quad (8)$$

Equation (7) can be used to obtain s_i . Equation (8) can be used to obtain f_{li} . Equation (6) can be used to obtain p_{li} .

The above formulae are used to estimate the transition probabilities p_{li} , r_{li} , and r_{2i} .

b. Computer simulation

Violations v_{li} are generated during each week of the simulation according to the transition probabilities p_{li} and r_{li} . An indicator variable is used to indicate if the violation is detected at time $t - 1$. Prior to detection, the true violations v_i are equal to the v_{li} . After detection, a v_i is set equal to zero if v_{li} equals zero. If v_{li} is not equal to zero, v_i is set equal to zero with probability $1 - r_i$. Because v_i has two chances to equal zero, r_i is related to the transition probability r_{2i} by

$$r_i r_{li} = r_{2i} \quad \text{or} \quad r_i = r_{2i} / r_{li}.$$

Once v_i is zero, v_i remains at zero until a new run of $v_{li} = 1$ begins. Flowcharts for the computer simulation of violations and detections are given in Section 3.

3. Detection Model

The inspection-enforcement model depends on the inspection plan. These plans were discussed in the previous chapter. The four options which can be used are satellite-airplane-man, satellite-man, airplane-man,

and manned inspection. Also, high altitude photography can be used as a surrogate for satellite photography. Because all of the options are similar, we will define the satellite-airplane-man inspection simulation. All of the options are included in a single computer program.

Assume a satellite inspection is made at the end of every period of s days. If the resulting electronic data gives a detection, assume that an aerial inspection is made a days after the satellite inspection. If the aerial inspection detects a violation, a surface inspection is made m days after the aerial inspection. The inspection procedure is illustrated in Figure 1.

Landsat I and Landsat II orbit in such a way that mines in western Kentucky can be accessed every nine days. Thus, when a satellite inspection procedure is used, the unit of time must be changed from one week to nine days. However, weather in Kentucky is such that only 30% of the accesses are 70% or better cloud-free. In the computer simulation, we have altered the nine-day access to a seven-day access and adjusted the frequency 0.30 by $7/9$ to maintain the same expected number of cloud-free accesses.

The probability of a detection under satellite-airplane-man inspection depends on the violation. If this probability were known for each violation, then previously derived formulae could be used to analyze the costs. Because a detection does not take place until a man inspection is made, and because there is a lag between satellite and man inspection, simulation is necessary. Because satellite and airplane "detections" serve only as a pointer for further inspection, airplane and satellite "detections" are denoted by quotes.

A violation can be misclassified by a satellite in two ways (see Figure 1, Appendix A) with the following misclassification probabilities:

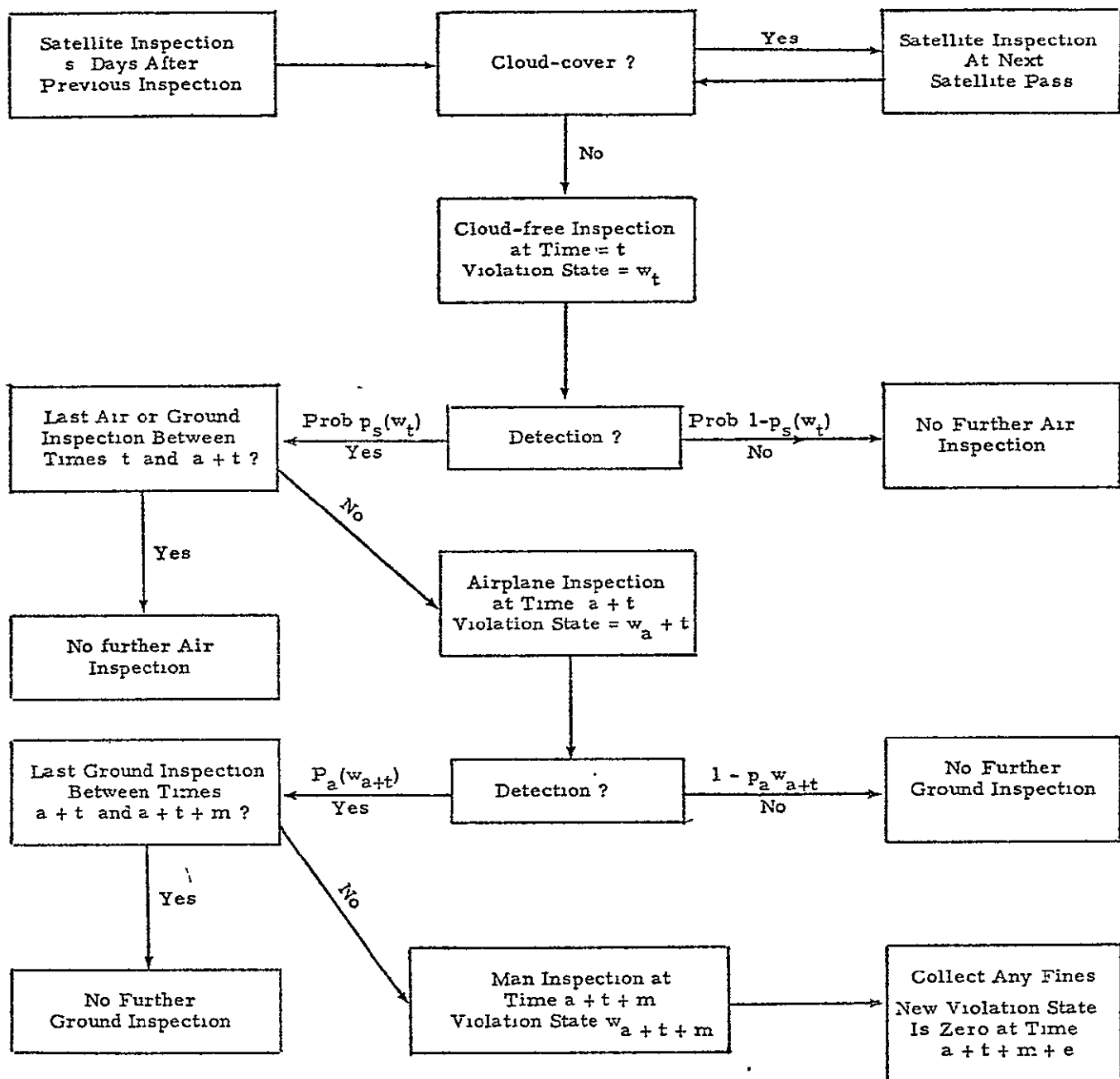


Figure 1. Satellite-Airplane-Man Inspection

$$\begin{aligned} \alpha_i &= p(\text{"detect" a nonexistent violation } v_i) \\ \beta_i &= p(\text{miss an existing violation } v_i) . \end{aligned}$$

The probability of a "detection" of v_i is given by

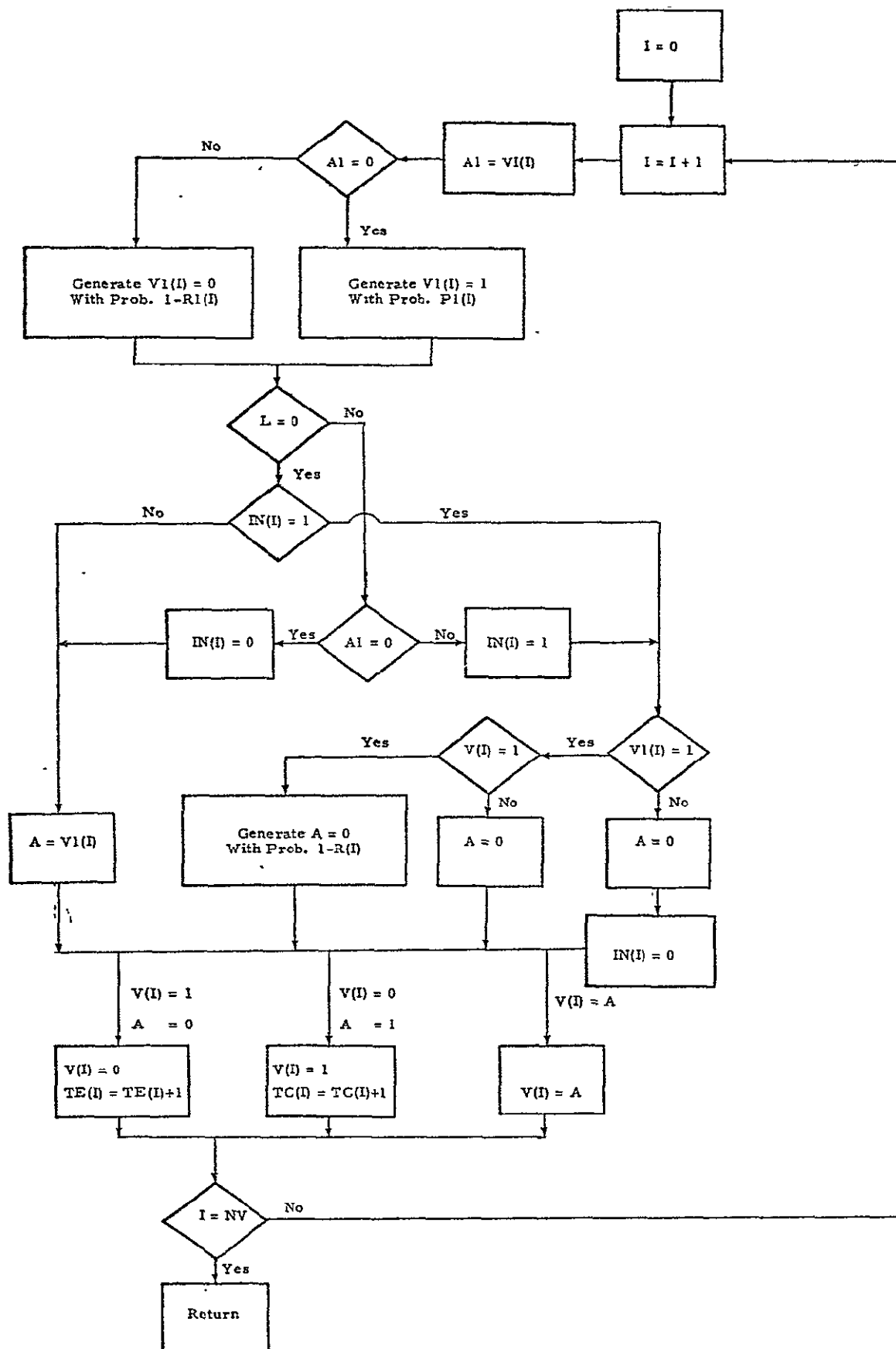
$$\begin{aligned} \gamma_i &= \alpha_i \quad \text{if } v_i \text{ does not exist} \\ \gamma_i &= 1 - \beta_i \quad \text{if } v_i \text{ exists.} \end{aligned}$$

The probability of a "detection", if independence is assumed among violations, is

$$p(\text{"detection"}) = 1 - \prod_{i=1}^n (1 - \gamma_i) .$$

Because the probability of "detection" depends on whether a satellite or airplane is used, and also depends on which violations are present, i. e., the state w of the mine, we have denoted this "detection" probability in Figure 1 by $p_s(w)$ for a satellite and by $p_a(w)$ for an airplane.

In the simulation, we have avoided using an airplane or man inspection when a satellite "detection" has occurred for those cases where an airplane or man inspection has already been made since the satellite pass. Such cases occur frequently when s is small (such as nine days) and a or m is large. A single airplane pass voids all satellite "detection" from satellite passes prior to the airplane pass. In Figures 2 and 3 we give flow-charts for the computer simulation. The flow-chart includes all four options of s-a-m, s-m, a-m, or man inspections. This flow-chart is for a single mine. In the next section, we show how the results of the simulation for a single mine are used to calculate the costs of an inspection plan for all the mines in western Kentucky. The flow-chart for the main simulation program of the cost/benefit study is given in Figure 4 of the next section.



$V1(I)$ = Value of violation at T if undetected
 $V(I)$ = Value of violation under inspection process
 $TE(I)$ = Number of times a string ends
 $TC(I)$ = Number of times a string begins
 A = Value of $V(I)$ at T
 $A1$ = Value of $V1(I)$ at T-1

Figure 2. Subroutine Violation Flowchart

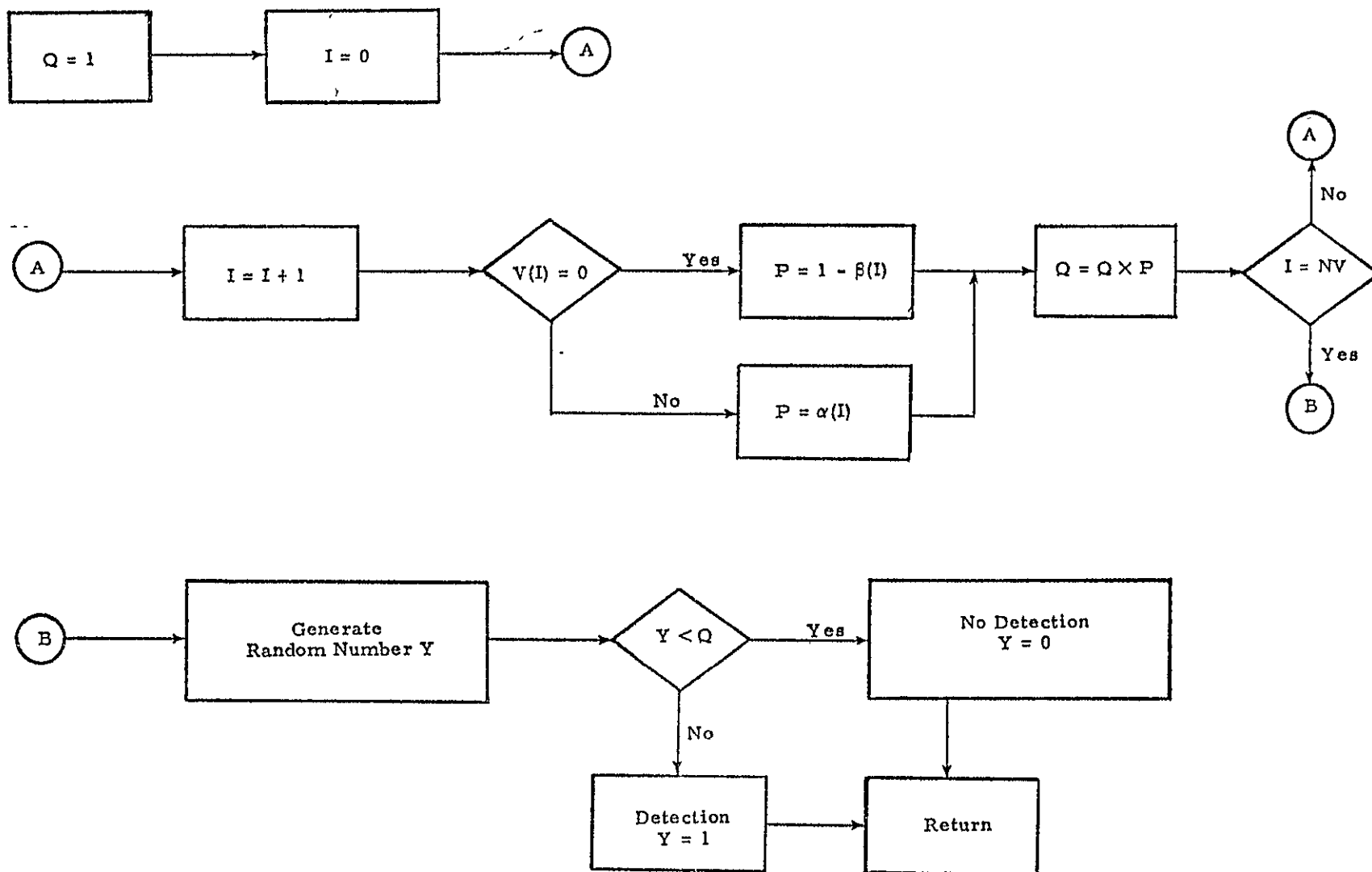


Figure 3. Subroutine Detection Flowchart

4. Total Costs Under an Inspection Program

As explained earlier, random numbers are used to determine the violation-inspection-detection state of a mine during any week. If a sufficiently long period of time is simulated, the average yearly cost should be approximately that which would be given by exact mathematical formulae, if such formulae were to be developed.

To calculate the costs, a tally is kept of the necessary parameters. The total cost is given by

$$\begin{aligned} \text{Cost} = & (c_v - F) \times N + c_s \times N_s + c_{a_1} \times N_{a_1} + c_{a_2} \times N_{a_2} \times N \\ & + c_m \times N_m \times N \end{aligned} \quad (9)$$

where

N	=	number of mines
c_v	=	total social costs of the violations for a single mine
F	=	total fines collected from a single mine
c_s	=	fixed cost of satellite inspection
N_s	=	number of cloud-free satellite inspections
c_{a_1}	=	fixed cost of airplane inspection
N_{a_1}	=	number of airplane passes
c_{a_2}	=	unit cost per mine for airplane inspection
N_{a_2}	=	number of airplane inspections at a single mine
c_m	=	cost per mine for man inspection
N_m	=	number of man inspections at a single mine

All of the variables above except N_{a_1} are computed by the simulation program. The total number of airplane passes differs from the number of aerial inspections at a single mine because only a portion of the mines are inspected at any time. An exact formula for N_{a_1} is derived below.

The fraction of times a cloud-free satellite inspection requires an aerial inspection at a given mine is

$$1 - \mu = \frac{N_{a_2}}{N_s}$$

The probability none of the mines requires an inspection is μ^N . An airplane pass is required if at least one mine requires an inspection. The expected number of airplane passes is, therefore

$$N_{a_1} = (1 - \mu^N) N_s$$

The most general method of calculating c_v is to assign weekly costs to each of the 2^n possible violation states $(v_1, v_2, \dots, v_n)$. No assumption about additivity of costs is made. By additive we mean the cost of simultaneously occurring violations is the sum of the individual costs of each violation. Additivity depends on the dissimilarity of violations. For example, the concurrence of a grading violation and a pit drainage violation probably represents additive costs. Vegetation "current" and vegetation "to plan" violations are so similar that the cost of one is equal to the cost of both.

After talking with inspectors, we have concluded that additivity can be assumed for the four violations revegetation, grading, drainage

control, and water quality. Accordingly, the simulation program has been modified to this assumption. The value of c_v is defined by

$$c_v = \sum c_{v_i} \times N_i$$

where

$$\begin{aligned} c_{v_i} &= \text{weekly cost of violation } V_i \\ N_i &= \text{number of weeks of occurrence of } V_i \end{aligned}$$

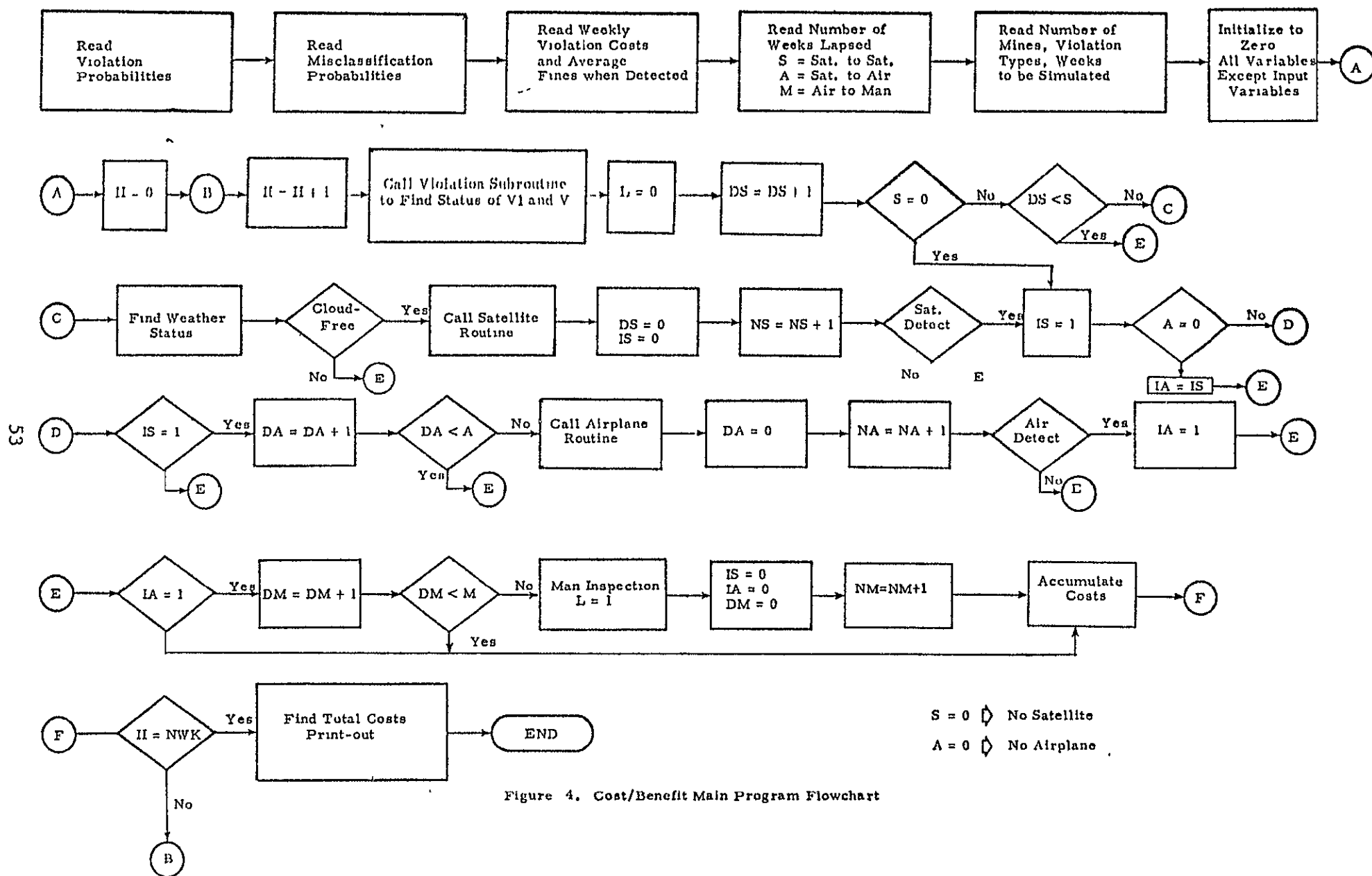
The total fine F is similarly defined by

$$F = \sum F_i \times N_i$$

where

$$\begin{aligned} F_i &= \overline{F}_i \times a_i \\ \overline{F}_i &= \text{average amount of fine for } V_i \\ a_i &= \text{frequency which a fine is collected} \\ &\quad \text{after detection} \end{aligned}$$

Because a variable number of weeks can be simulated (for example, 10 years), all of the costs printed out are scaled down to yearly costs, using the scale 52/(no. of weeks). In anticipation of further mathematical modelling for developing an optimal inspection procedure, the computer is also programmed to print out other variables such as the average number of runs of violations per year, their average duration, and the number of runs detected. A flow-chart of the main program for the costs of violation-inspection-enforcement processes is given in Figure 4.



IV. AN ANALYSIS OF THE INSPECTION OF STRIP MINES
IN WESTERN KENTUCKY, 1971-74

1. Violation Durations

In a separate report for this contract (Appendix B), MATHEMATICA has done a detailed analysis of mine inspection data for the years 1971-74. An analysis of such data is important in estimating the frequency of violations at strip mine. The cost/benefit model developed in Chapter III depends on such frequencies. In the inspection process report, inspection and violation frequencies were calculated for each of twelve types of violations. Because the estimation of rehabilitation and social costs and the estimation of detection probabilities becomes increasingly more complex as more violation types are used, Claude Downing of the Western Kentucky Area Reclamation office in Madisonville was asked to select the four most important categories from the twelve. These are as follows:

Violation Type	Original Violation Type
Revegetation	Vegetation Current Vegetation Regulation
Grading	Grading Current Grading to Plan
Water Quality	Water Quality Chemical
Drainage Control	Silt Structure Drainage Plan
Not considered	Access Road Water Impoundment Water Quality Physical

Appendix B, presents an analysis of the inspection and violation frequencies for the period 1971-74. Tables in this Appendix can be used for estimating the frequencies of the occurrence of violations in Section 3. These tables can also be used to determine if the four major violation types listed above are sufficient for the model. Referring to table 11A (Appendix B), ignoring the Method of Operation and Discrepancies, the sum of the marginal probabilities of all the violations is 0.8301. The violation types not considered in the model are marginal probabilities adding to 0.0626. About seven percent of the violations are, therefore, ignored; however, this is perhaps an over-estimate because the omitted violation types are correlated with the others. Also referring to Table 15 (Appendix B), it can be seen that the three pairs listed above under Revegetation, Grading and Drainage Control rated the highest of all interaction pairs. (Interactions with Method of Operation must be excluded because, by definition Method of Operation violations occur whenever other violations occur.)

To estimate the frequencies of violations from the inspection analysis report (Appendix B), two of the following three expected durations must be known for each of the four major violations:

- L_1 = Expected duration of a violation under no inspection process
- L = Expected duration of a violation under the 1971-74 inspection process
- L_2 = Expected duration of a violation after it has been detected.

Claude Downing of Madisonville and Bill Kelly at MATHEMATICA have aided in supplying the following expected durations of violations.

Violation Type	Expected Duration No Inspection L_1	Expected Duration* After Inspection L_2
Grading	6 months	3 months
Revegetation	8 months	4 months
Water Quality	1 week	1 week
Drainage Control	6 months	1 month

The annual permit regulations are such that all violations can be presumed to last a year. If violations begin randomly, under the assumption that the miners do not correct the violations until necessary, the expected duration is six months or 180 days. This explains the 6 month expected duration for grading and drainage control. The water quality expected duration of violation of 7 days is only approximate. If there is an improper chemical treatment of the water, the resulting poor water quality occurs only during period of heavy rainfall runoff or pit drainage.

Revegetation violations last longer than other violations because seeding takes place during two-month intervals followed by four-month non-seeding intervals. Thus, the minimum duration of a revegetation violation is four months.

The expected duration of detected violations is not to be confused with L_2 . Detected violation have an expected duration L_2^ equal to the sum of L_2 plus the expected duration prior to detection. Because some violations may not be detected, the expected duration L under a policy is between L_1 and L_2^* .

We will use the above expected durations to calculate theoretical frequencies for the four major violation types in the next section. Because inspections are made separately at each permit area, the total number of permitted areas are used in the estimates and in the detection model. Figures from the Kentucky Department of Mines and Minerals, 1974 Annual Report give the following:

Surface Mining in Western Kentucky	
87 strip mines	94 new permits
<u>3 auger strip mines</u>	104 supplements
90 surface mines	34 renewals
	20 deferrals

The total number of permitted areas in 1974 is the sum of the 94 new permits plus 34 renewals, or 128.

2. Violation Frequencies Under the 1971-74 Ground Inspection Process

The relative frequencies and number of detected occurrences of each of the four violation types are computed from the tables in Appendix B by using the formulae

$$P(AB) = P(A)P(B \text{ given } A)$$

$$\#(AB) = P(AB) \times \#(\text{inspections})$$

For example, the number of times grading current and grading to plan were detected simultaneously is

$$0.2493 \times 0.3982 \times 2760 = 274$$

Similar calculations give the following:

Violation Type		Number of Detections
Grading Current?	Grading to Plan?	
Yes	Yes	274
Yes	No	825
No	Yes	32
No	No	1,629
Total Inspections		2,760

Thus a grading violation was observed with frequency

$$f_g = \frac{1,131}{2,760} = 0.4098 .$$

Some adjustments were made on the remaining three observed violation frequencies. These adjustments account for observed correlations and an increasing trend in detections during the 1971-74 period. The purpose of adjustments for correlations is to make the assumptions of cost additivity and independence more plausible.

Yearly Trends

In Appendix B, it is shown that water quality and revegetation incidents increased during the years 1971-74. By multiplying the frequencies by the number of inspections for each year, we get the following table:

Year	Method of Operation	Water Quality	Vegetation	Number Inspections
1971	389	34	0	721
1972	361	86	4	745
1973	180	122	31	525
1974	262	242	101	769
Total	1,192	484	136	2,760

Revegetation and vegetation violations probably did not increase during 1971-74. On the contrary, interviews with inspectors suggest that the reason more incidents are occurring is that inspections are becoming more rigorous.

Thus, at the 1974 rate, we estimate that revegetation violations were observed with frequency

$$f_v = \frac{101}{769} = 0.1313$$

Revegetation violations were found to vary seasonally (Appendix B). This can be explained by the fact that violations can begin or end only in the Spring or Fall seeding seasons. Thus, no adjustments need be made for any seasonal inconsistency of the reporting of incidents.

Water quality chemical and drainage control both fall under the category "water quality" in the inspection analysis report [3]. Assuming some violations were not reported as rigorously during 1971-73 as 1974, the frequencies of these violations for 1971-74 should be scaled up by the factor

$$\frac{242}{769} \div \frac{484}{2,760} = 1.7945$$

From Table-11A (Appendix B), we estimate the 1974 rate of water quality chemical violations to be

$$f_{wq} = 0.0308 \times 1.7945 = 0.0552$$

Besides scaling by the factor 1.7945, drainage control violations must be adjusted further to account for correlations with other violation types.

The adjusted frequencies are developed next.

Drainage Control

Drainage control consists of the two violation types "silt structure" and "drainage plan." Silt structure was observed to be highly correlated with revegetation. Drainage plan is highly correlated with grading. Because there is no obvious causal relation between silt structure and revegetation, this correlation is ignored. However, drainage plan in some cases is more closely associated with grading than with drainage control. The table below illustrates this correlation.

Violation	Number Observed	Number Observed with Drainage Plan	Expected Number Under Independence
Grading Current	1,099	106	80
Grading To Plan	306	52	22
Total	1,405	158	102
Grading	1,131	127*	82*

* The values 127 and 82 are estimated by scaling 158 and 102 by 1131/1405.

To obtain independence, the original 127 observed drainage plan violations which occurred with grading violations must be reduced. This is done by adjusting the first column in the following table to values β and $1131 - \beta$ in such a manner that

$$\frac{\beta}{1131} = \frac{73 + \beta}{2760} \quad (\text{solution: } \beta = 51)$$

Parentheses denote the original values.

Violation Type	Grading Violation	No Grading Violation	Total
Drainage Plan Violation	(127) 51	(73) 73	(200) 124
No Drainage Plan Violation	(1,004) 1,080	(1,556) 1,556	(2,560) 2,636
Total	1,131	1,629	2,760

Then, for example, the conditional probability $\frac{51}{1,131}$ is equal to the marginal probability $\frac{124}{2,760}$. To obtain the table below, we have modified the original marginal probability for drainage plan to 124/2760. Parentheses denote the original values.

Violation Type		
Silt Structure?	Drainage Plan?	Observed Number
Yes	Yes	45 (73)
No	Yes	79 (127)
Yes	No	182 (154)
No	No	2,454 (2,406)

Total Number Drainage Control Violations = 306

Scaled-up = 549

The scale-up factor for adjusting all 1971-74 water quality violations to the 1974 level is 1.7945. The estimated frequency for drainage control violations for use in our model at the 1974 inspection rate is thus

$$f_{dc} = \frac{306}{2,760} \times 1.7945 = .1990.$$

The frequencies f_g , f_v , f_{dc} , and f_{wq} are estimates of the probabilities of the existence of violations at any time under man inspection rates given by the 1971-74 inspection data. Other parameters for this inspection rate are given by equations (1)-(8) of Chapter III. For example, the frequency of starts of runs of grading violations is estimated by

$$s_g \times L_g = f_g = 0.4098$$

where the average length L_g is defined by equations (1)-(3). Note that

s_g and L_g are dependent on the unit of time while f_g is not. For example, if the unit of time is changed from one week to one day, s_g is divided by seven and L_g is multiplied by seven. To estimate the frequencies of violations for different inspection processes, we need the 1971-74 inspection rate. During 1971-74 there were 301/4 mines per year in operation. This number is scaled up by 124/90 to obtain an estimate of the number of permitted areas. (There were 90 mines operating at 124 permitted areas in 1974). Thus the frequency of inspection per permit area per week in 1971-74 is estimated to be

$$\bar{p}_D = \frac{2760}{301 \times 52} \times \frac{90}{124} = 0.127985.$$

Table 1 lists the violation parameters calculated from equations (1)-(10) and the inspection rate $\bar{p}_D$ and the estimated violation parameters L_1 , L_2 , and f . These parameters are given for the one week time intervals used in the computer simulation. In Chapter V, units of time are refined to one-day intervals to estimate the optimal manned inspection rate. The violation parameters when the unit of time is one day are given in Table 9.

Social costs of violations are defined in this report as the cost of the damage to the environment while the violation type persists. Thus, the total social cost is known if the frequency and cost per unit time for the violations is known. In Chapter V, Section 1, social cost estimates are given. Yearly social costs corresponding to the 1974 inspection rate (average duration = L), daily inspection rate (average duration = L_2) and yearly inspection rate (average duration = L_1) are given in Tables 6, 7, and 8.

The total costs include, of course, not only the social costs, but also the inspection costs plus any terminal costs or benefits such as

Table 1. Estimated Prior and Posterior Frequencies for Detection Model*
When Violations Generated Each Week

Description of Parameter	Parameter	Grading	Revegetation	Drainage Control	Water Quality
Prior expected length under no inspection	L_1	26.00	34.67	26.00	1.0
Expected length for inspection process 1971-74	L	15.70	20.18	8.57	1.0
Posterior expected length after detection	L_2	13.00	17.33	4.00	1.0
Prior transition probability given violation previous week	r_1	0.9615	0.9712	0.9615	0.0
Transition probability given violation previous week for inspection process 1971-74	r	0.9363	0.9504	0.8833	0.0
Posterior transition probability given violation and detection	r_2	0.9231	0.9423	0.7500	0.0
Prior transition probability given no violation previous week	p_1	0.0812	0.0084	0.0586	0.0584
Transition probability given no violation previous week under inspection process 1971-74	p	0.0442	0.00749	0.0290	0.0584
Frequency of violations under no inspections	f_1	0.6787	0.2256	0.6039	0.0552
Frequency of violations under inspection process 1971-74	f	0.4098	0.1313	0.1990	0.0552
Frequency of start of new runs of violations	s	0.0261	0.00651	0.0232	0.0552

* Estimates are based on 1971-74 inspection process with an assumed rate of inspection of $p_D = 0.12798529$ permitted areas inspected per week

rehabilitation costs to the Commonwealth, fines, and bond forfeitures. In Section 3 of Chapter V, these costs are included to determine an optimal manned inspection policy.

V. COST/BENEFIT ANALYSIS - MANNED INSPECTION

1. Social Costs

There are several approaches to measuring the social costs arising from mining violations. For example, Howard [16] apportions U. S. Public Health Service estimates of social costs of acid mine water for mining in Appalachia into percentages for different categories. In his economics model, Howard allows for changes in mining practices, he discounts all years to a base year, and he allows for decreasing costs as nature corrects damages. The coefficients used in his model are necessarily subjective estimates obtained from consultation with personnel of the Kentucky Reclamation Division and others.

The University of Kentucky is currently doing a social cost study of strip mining for the Environmental Protection Agency, but, as yet, no data is available from this study. (The data for Appalachia in Howard's study was derived by the U. S. Public Health Service from a projection of a survey done in 1940. More recent studies such as the University of Kentucky's will be useful for future cost/benefit analyses based on methodology similar to that developed by Howard.)

Another method of estimating social costs, commonly used in the past, is to equate social costs with the costs of removing the source of the damage. Social costs are now recognized to have the cost of rehabilitation as only one component. The other component is a function of the amount of time during which the damaging effects take place. For example, as an estimate of the cost of sedimentation, Howard estimates the cost of removal of such material. Unless the sedimentation had

no effects on the environment before its removal, Howard's estimate is only one component of the cost.

Dials and Moore (12) give a report on the cost of coal in terms of damages to the environment and the health to individuals. Their article is very thorough in describing the types of damages and in giving some subjective gross figures for the costs of surface and deep mining in the United States. Dials and Moore, for example, estimate from Department of Interior 1970 data the cost of treating the then-existing 1970 acid mine drainage to be \$0.392 per ton for surface mined coal. Unfortunately, we are not interested in the cost of abating acid mine drainage, but instead in the social cost to the environment while water quality or drainage violations persist.

None of the literature which we have researched can be used to assess the cost of violations on a permit area and on a per week basis for mines in western Kentucky. The available costs are in terms of abatement and rehabilitation. If per day costs were available for mines in an area similar to western Kentucky, it would still be necessary to know the violation characteristics (frequency, duration, seriousness) and the components of the costs due to these violations, to estimate the required social costs. For this reason, MATHEMATICA has developed estimates through subjective scores assigned to the violations by inspectors from western Kentucky. With these scores, it is only necessary to know the cost of any one of the violations in order to estimate all of them.

Of the four violation types, the cost of a revegetation violation is the simplest to assess. We can ignore revegetation costs to the Commonwealth because permit renewal and bond release regulations

force most mine operators to revegetate. One cost of a revegetation violation is the added expense in revegetation because of soil compaction and erosion. But this is a cost to the mine operator and not to the Commonwealth. Lack of vegetation increases acid mine drainage and sedimentation, but such costs are included in the water quality and drainage control costs and should be ignored to avoid double counting. We can also ignore the cost from aesthetic considerations because this value is constant for a mining area independent of the number or type of violations. If topsoil were required to be saved and replaced after mining, erosion and soil degradation would be important. This is not required at the present. The remaining cost is the delay in the land being useable for plant and/or wildlife. While mining operators do not usually rent their land, land in the active mining regions is rented at a rate of about \$50 a year per acre. Revegetation violations average about 25 acres. (Estimated by Claude Downing.) Thus, an average revegetation violation costs \$24.04 per week.

The figure of \$24.04 per week for a revegetation violation is used as a base to estimate the costs of other violations. When still at the Department for Natural Resources and Environmental Protection, William Kelly asked the then ten inspectors of western Kentucky to rank violations according to the degree of seriousness, by values from zero to ten. The sum of the scores made by the inspectors gives total scores whose values are between zero and one hundred. Table 2 gives these total scores.

Assuming that the danger to life and property and environmental scores are weighted proportionately to the inspector's subjective estimates of social costs, each of the costs of violations can be estimated from the total cost of a revegetation violation. The scale factor used

to determine the social costs depends on the average duration of violation the inspectors had in mind. Three alternative social costs are given in the following tables. In each table, the total costs are proportional to the total scores.

Unique social costs do not exist. Because social cost estimates vary among people, it is useful to use several costs to ascertain the sensitivity of the analysis to the costs. While we will use as costs the values in Table 3, we will use the costs in Tables 4 and 5 as a check for the robustness of the optimal strategy. Grading and revegetation costs are known with higher accuracy than the remaining two. Because the assumption is made in the initial application of the model that water quality violations are not affected by the inspection process (except in the amount of fines), the optimal inspection strategy is not sensitive to the social costs of water quality. Thus, the unknown cost variable is drainage control. The range of \$60.67 to \$197.17 per week should adequately cover this cost.

Table 2. Violation Scores by Western Kentucky Inspectors

Violation	Danger to Life or Property	Environmental Impact	Deliberateness by Mining Operators	Ability to be Corrected
Grading not current	23	44	61	87
Water quality regulation	80	88	80	24
Exposed Reject Material (acid shale)	39	71	47	65
Revegetation not current	26	58	60	75
Violation of 100 ft. zone	79	58	86	33
Material off permit area	75	52	66	20
Working off permit area	58	56	69	44
Access Road	48	35	46	58
No silt structure	66	93	70	44

Table 3. Estimated Social Costs Based On Inspector's Scores
 Using Average Duration of Violations During 1971-74

Violation	Average Duration (Weeks)	Danger to Life and Property	Environmental Impact	Total Score	Total Cost	Cost per Week
Grading	15.7	23	44	67	\$386.92	\$24.64
Revegetation	20.18	26	58	84	\$485.10	\$24.04
Drainage Control	8.57	66	93	159	\$918.22	\$107.14
Water Quality	1	80	88	168	\$970.19	\$970.19

Table 4. Estimated Social Costs Based On Inspector's Scores

Using "Worst-Case" Average Duration

Violation	Worst-Case Average Duration (weeks)	Total Score	Total Cost	Cost per Week
Grading	26	67	\$ 664.68	\$ 25.56
Revegetation	34.67	84	833.33	24.04
Drainage Control	26	159	1577.38	60.67
Water Quality	1	168	1666.67	1666.67

Table 5. Estimated Social Costs Based on Inspector's Scores

Using Average Duration After Detection

Violation	(weeks) Duration after Detection	Total Score	Total Cost	Cost per Week
Grading	13	67	\$332.34	\$25.56
Revegetation	17.33	84	416.67	24.04
Drainage Control	4	159	788.69	197.17
Water Quality	1	168	833.33	833.33

The total costs of a violation type during the year are obtained from the formula

$$\begin{aligned} \text{cost per year of violation type} &= \{ \text{cost per week of violation} \} \\ &\times \left\{ \begin{array}{l} \text{frequency of occurrence} \\ \text{per week per permitted} \\ \text{area} \end{array} \right\} \\ &\times \{ \text{number of permitted areas} \} \\ &\times \{ 52 \text{ weeks per year} \} \end{aligned}$$

For the number of permitted areas, we will use the value of 124 for 1974. Tables 6, 7, and 8 illustrate cost computations using the cost estimates given in Tables 3, 4, and 5 and the frequency estimates given in Table 1. In Tables 6, 7, and 8 a violation is counted once per week of occurrence. If a violation occurs during L consecutive weeks and does not occur on the $(L + 1)^{\text{st}}$ week, then one run of length L has occurred. The total social cost of a violation is defined by

$$\text{cost} = (\text{cost per week of violation}) \times \text{number of violations}$$

and

$$\text{number of violations} = \text{number of runs} \times \text{average length of a run}$$

Similar computations are necessary to compute the optimal inspection strategy. Formula computations, and results are given in the next two sections.

Table 6. The Frequency and Costs of Violations
Under 1974 Inspection Process

Violation	Number of Runs of Violation Per Year Per Permit $s \times 52$	Average Length of a Violation Run L (weeks)	Number of Weeks of Violation Per Year Per Permit $52 \times f$	Total Cost of Violation Per Year Per Permit	Total Cost of Violation Per Year Per 124 Permits
Grading	1.357	15.699	21.310	\$ 525.07	\$ 65,108
Revegetation	0.338	20.180	6.827	164.13	20,352
Water Quality	0.055	1.000	2.870	2,784.83	345,319
Drainage Control	1.208	8.568	10.348	1,108.70	137,749
Total					\$568,258

Table 7. The Frequency and Costs of Violations
Under Daily Inspection.

Violation	Number of Runs of Violation Per Year Per Permit $s \times 52$	Average Length of a Violation Run L (Weeks)	Number of Weeks of Violation Per Year Per Permit $52 \times f$	Total Cost of Violation Per Year Per Permit	Total Cost of Violation Per Year Per 124 Permits
Grading	1.357	13.000	17.646	\$ 434.79	\$ 53,914
Revegetation	0.338	17.333	5.864	140.97	17,481
Water Quality	0.055	1.000	2.870	2,784.83	345,319
Drainage Control	1.208	4.000	4.831	517,59	64,182
Total					480,896

Table 8. The Frequency and Costs of Violations
Under Yearly ("Worst-Case") Inspection.

Violation	Number of Runs of Violation Per Year Per Permit $s \times 52$	Average Length of a Violation Run L	Number of Weeks of Violation Per Year Per Permit $52 \times f$	Total Cost of Violation Per Year Per Permit	Total Cost of Violation Per Year Per 124 Permits
Grading	1.357	26.000	35.291	\$ 869.58	\$107,827
Revegetation	0.338	34.667	11.728	281.94	34,961
Water Quality	0.055	1.000	2.870	2,784.83	345,319
Drainage Control	1.208	26.000	31.402	3,364.36	417,181
Total					\$905,288

2. Ground Inspection Parameters

Two sets of parameters for the frequency of violations will be used in the cost/benefit study. For computer simulations, the time axis must be partitioned into units of one week intervals. For ground inspection only a unit of time equal to one day will be used. Using a daily rate for computer simulations would entail seven times as much computer time, with insignificant changes in the results for aircraft or satellite inspection strategies. Significant differences occur between daily rate and weekly rate calculations only when the weekly inspection rate is close to or greater than one. (A value of $P_D = 3.5$ inspections per week must be changed to .5 inspections per day to define a probability.) In Table 9, we have given the daily rates for the generation of violations. These are obtained from knowledge of L_1 , L_2 , f and the formulae of Chapter III.

A variable which affects the optimal inspection frequency is the average duration of a water quality violation. The average duration may be as short as three days. As a sensitivity analysis, we have used both three days and seven days for water quality violations. At the three day rate, the total number of runs is increased, the cost per week is increased (total cost per run remains the same), and the detection probability of a run is decreased.

By using the formulae in Chapter III, an optimal manned inspection policy can be determined without computer simulation. A sensitivity analysis is also made to determine the effects on the optimal policy of changes in the cost parameters and violation frequencies.

Table 9. Estimated Prior and Posterior Frequencies
for Detection Model When Violations are
Generated Daily

Parameter	Grading	Revegetation	Drainage Control	Water Quality If 3 Days	Water Quality If 7 Days
L_1	182.00	242.67	182.00	3	7
L	109.90	141.26	59.98	3	7
L_2	91.00	121.33	28.00	3	7
r_1	0.9945	0.9959	0.9945	0.6667	0.8571
r	0.9909	0.9929	0.9833	0.6667	0.8571
r_2	0.9890	0.9918	0.9643	0.6667	0.8571
p_1	0.0116	0.000120	.00838	0.0195	0.00835
p	0.00632	0.00107	.00414	0.0195	0.00835
f_1	0.6787	0.2256	0.6039	0.0552	0.0552
f	0.4098	0.1313	0.1	0.0552	0.0552
s	0.00373	0.9294×10^{-4}	0.0033	0.0184	0.00788

Fines are important because they partially cover the costs of inspection. The only fines collected in the past, which have any significance, for the four violations are the fines for water quality violations. As an estimate of the frequency and amount of such fines, Claude Downing suggests about twelve fines per year at the 1974 inspection rate, with an average of \$5,000 per fine. We will assume a fine is collected at most once per detection of a run of violations. If a water quality violation lasts L units of time, and inspections are made at a frequency p_D , then the probability of detecting a water quality violation at least once is

$$w_L = 1 - (1 - p_D)^L$$

The probability of detecting a water quality violation at least once is

$$w = \sum_{L=1}^{\infty} w_L r^{L-1} (1-r) = \frac{p_D}{1 - r + p_D r} \quad (10)$$

At the 1971-74 inspection rate,

$$p_D = 0.0182836 \text{ inspections per permit per day}$$

$$r = 1 - 1/7 = 0.857143$$

$$w = 0.115333$$

$$s = \frac{0.0552}{7} = 0.007886$$

The frequency of detections of water quality violations when detections are counted once per run is

$$w \times s \times 52 \times 7 \times 124 = 40.91656$$

Of this number, 12 fines were collected. Thus, the probability that a water quality run of violations results in a fine is estimated to be

$$\frac{12}{40.91656} = 0.2932798$$

For every detection of a run of water quality violations, we therefore estimate the average fine collected to be

$$5000 \times 0.2932798 = 1466.3989$$

By using this average fine, the total fine collected under different man inspection frequencies P_D can be calculated using equation (10) for w. The total fine collected is $w \times s \times 52 \times 7 \times 124$.

The cost of man inspections for the base year 1974 is determined from the following figures:

1974 Division of Reclamation Budget excluding research	\$1,085,141
Travel, gas and oil, vehicle maintenance	<u>139,141</u>
Total personnel and overhead excluding research, travel & vehicles	\$ 945,559
Personnel salaries plus fringe benefits	\$ 785,306
Fringe benefit rate	16.1%

The total amount of salaries is then

$$\frac{785,306}{1.161} = \$676,405$$

and the overhead rate is

$$\frac{945.59}{676.405} = 1.397184$$

The average inspector salary in 1974 was about \$750 per month. Claude Downing estimates that each inspector can inspect 40 mines per month at a rate of 3/4 time for inspection and 1/4 time for other activities such as permitting. This gives a cost per inspection plus overhead to be

$$\frac{750}{40} \times \frac{3}{4} \times 1.397184 = \$19.64$$

The total vehicle miles per month per inspector is approximately 2500 miles or 65 miles per inspection. At an allowance of 13.5¢ per mile, this gives travel costs of \$8.77. Thus, the total cost per inspection is estimated to be

$$c_m = \$28.40$$

The cost \$28.40 is based on the assumption that ten inspectors can make a total of 400 inspections per month per permit area. This inspection rate may be high. During 1971-74 an average of only 57.5 inspection reports were filed each month for Western Kentucky. An estimated 149.5 additional inspections per month were not reported. (See Section 4, Chapter V for an explanation of the adjusted estimate of 207 inspections per month.) Inspection reports are now required to be written for each inspection. Because this is an extra burden on the inspector, future inspection rates could be less than 207 inspections per month. An alternative estimate of the cost per inspection is

$$\$19.64 \times \frac{400}{207} + \$8.77 = \$46.72$$

As a sensitivity analysis, we will use an upper value of $c_m = \$50.00$.

3. Optimal Ground Inspection Policy and Sensitivity Analysis

For any inspection rate, the average duration L of a violation is given by equation (3). The total yearly cost of a violation is given by $s \times L \times 365 \times 124$ where s is the frequency of runs and the value 124 is the assumed number of permitted areas. For determining the optimal frequency of inspections of mines, the value of 124 permitted areas is not important because all costs are proportional to this number. Hence, the minimum costs are obtained at the same inspection frequency per permit area independent of the total number of permitted areas. Other costs needed are fines and costs of inspections. The formula for the total yearly amount of fines has been defined in Section 2. The cost of man inspection is given by $c_m \times N_m$ where N_m is the number of inspections. If inspections are made on the average once every d days per permit then:

$$N_m = p_D \times 365 \times 124$$

where $p_D = 1/d$

is the inspection frequency per permit.

To determine the optimal value of p_D , costs are calculated by the computer until a minimum total cost is obtained where:

$$\text{total cost} = \text{cost of violations} + \text{costs of inspection} - \text{fines}$$

The optimal value of p_D has been calculated using five social cost options, two water quality violation rates, and two costs per inspection. The purpose for generating several optimal values for p_D is not because of uncertainty of the best estimates, but instead to measure the sensitivity of the optimal value of p_D when departures from these estimates occur.

The five social cost options for the tables are defined in Table 10 and have been held fixed, the optimal rate of inspections d has varied less than one day. In Tables 11-16 the minimum cost for the inspection process is between seven and eight days. Thus under the assumptions made in Tables 9 and 10, a rate of 7.5 days between inspections is optimal under any of the five definitions of social costs.

Because of the robustness of the 7.5-day inspection rate, it appears that the inspection process is very sensitive to water quality violations. All other violations are less costly, are of much longer duration, and thus do not start as frequently. The high frequency of starts of water quality violations is important because each new start requires a new detection.

Communications with Claude Downing have led to the conclusion that a seven day length for water quality violations is maximum and that average lengths of three days should be used both for comparison and for better estimates of costs.

At the three-day length, water quality violations are more costly. That is, each run still costs the same total amount, but there are more runs. The last column of table gives the cost per week (not per length of violation) of water-quality violations under the three-day assumption.

The rate of fines collected, defined in Section 2, for seven-day violations must also be adjusted when the duration is changed to three days. The assumed rate of 12 fines of \$5,000 each for 1974 implies the average rate of collection of fines decreases when the number of runs increases. These calculations are automated by a computer.

The optimal inspection policy, calculated under the five social costs options again shows robustness. The optimal frequency in every

Table 10. Optional Estimates of Social Costs
Used in the Sensitivity Analysis

Method of Estimation Used in Tables	Cost/Week				
	Grading	Revegetation	Drainage Control	Water Quality @ 7-Day Duration	Water Quality @ 3-Day Duration
Option 1 Best Estimate: Costs Scaled to Average Duration During 1974, L	24.64	24.04	107.14	970.19	2263.78
Option 2 Costs Scaled to Duration After Detection, L ₂	25.56	24.04	197.17	833.13	1943.97
Option 3 Costs Scaled to Worst-Case Duration, L ₁	25.56	24.04	60.67	1666.67	3888.90
Option 4 Best Case: All Costs at Minimum Bound	24.64	24.04	60.67	833.13	1943.97
Option 5 Worst Case: All Costs at Maximum Bound	25.56	24.04	197.17	1666.67	3888.90

Table 11. Costs of Violations and Inspections -

Social Costs Scaled to 1974 Average Durations

Option 1

NO. INSP. PER DAY	COST OF VIOL.	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	480895.	1281861.	520232.	1242524.	1.
0.500	483190.	640931.	455203.	668918.	2.
0.333	485461.	427287.	404625.	508122.	3.
0.250	487707.	320465.	364163.	444009.	4.
0.200	489929.	256372.	331057.	415245.	5.
0.167	492128.	213644.	303469.	402302.	6.
0.143	494303.	183123.	280125.	397301.	7.
0.125	496456.	160233.	260116.	396572.	8.
0.111	498586.	142429.	242775.	398240.	9.
0.100	500694.	128186.	227602.	401279.	10.
0.091	502780.	116533.	214213.	405100.	11.
0.083	504845.	106822.	202312.	409354.	12.
0.077	506888.	98605.	191664.	413829.	13.
0.071	508911.	91561.	182081.	418391.	14.

NO. INSP. PER DAY	GRADING	REVEGETATION	DRAINAGE	WATER Q.	TOTAL
1.000	53914.	17481.	64182.	345319.	480895.
0.500	54208.	17552.	66111.	345319.	483190.
0.333	54500.	17623.	68019.	345319.	485461.
0.250	54788.	17694.	69906.	345319.	487707.
0.200	55073.	17764.	71773.	345319.	489929.
0.167	55355.	17833.	73620.	345319.	492128.
0.143	55634.	17902.	75448.	345319.	494303.
0.125	55911.	17971.	77256.	345319.	496456.
0.111	56184.	18038.	79045.	345319.	498586.
0.100	56454.	18106.	80815.	345319.	500694.
0.091	56722.	18172.	82567.	345319.	502780.
0.083	56987.	18239.	84301.	345319.	504845.
0.077	57249.	18304.	86017.	345319.	506888.
0.071	57508.	18369.	87715.	345319.	508911.

Table 12. Cost of Infrequent Inspections
Social Costs Scaled to 1974 Average Durations
Option 1

NO. INCP. PEP DAY	COST OF VIOL'S	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
0.143	494303.	183123.	280125.	397301.	7.
0.071	508911.	91561.	182081.	418391.	14.
0.048	522514.	61041.	134875.	448680.	21.
0.036	535212.	45781.	107107.	473886.	28.
0.029	547094.	36625.	88820.	494898.	35.
0.024	558234.	30521.	75867.	512888.	42.
0.020	568702.	26160.	66211.	528651.	49.
0.018	578556.	22890.	58736.	542710.	56.
0.016	587848.	20347.	52777.	555417.	63.
0.014	596625.	18312.	47916.	567021.	70.
0.013	604930.	16648.	43875.	577702.	77.
0.012	612798.	15260.	40462.	587595.	84.
0.011	620264.	14086.	37542.	596809.	91.
0.010	627358.	13080.	35016.	605422.	98.
0.010	634107.	12208.	32807.	613508.	105.
0.009	640536.	11445.	30861.	621119.	112.
0.008	646666.	10772.	29133.	628305.	119.
0.008	652519.	10174.	27588.	635104.	126.
0.008	658113.	9638.	26199.	641551.	133.
0.007	663463.	9156.	24943.	647677.	140.
0.007	668587.	8720.	23601.	653505.	147.
0.006	673498.	8324.	22760.	659061.	154.
0.006	678210.	7962.	21806.	664365.	161.
0.006	682733.	7630.	20929.	669434.	168.
0.006	687080.	7325.	20119.	674285.	175.
0.005	691259.	7043.	19370.	678931.	182.

Table 13. Costs of Violations and Inspections

Social Costs Scaled to Duration After Detection

Option 2

NO. INSP. PEP DAY	COST OF VIOL'S	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	488056.	1281861.	520232.	1249685.	1.
0.500	491983.	640931.	455203.	677711.	2.
0.333	495868.	427287.	404625.	518530.	3.
0.250	499711.	320465.	364163.	456014.	4.
0.200	503513.	256372.	331057.	428828.	5.
0.167	507274.	213644.	303469.	417449.	6.
0.143	510995.	183123.	280125.	413993.	7.
0.125	514678.	160233.	260116.	414794.	8.
0.111	518321.	142429.	242775.	417975.	9.
0.100	521927.	128186.	227602.	422512.	10.
0.091	525496.	116533.	214213.	427815.	11.
0.083	529027.	106822.	202312.	433536.	12.
0.077	532522.	98605.	191664.	439462.	13.
0.071	535982.	91561.	182081.	445462.	14.

NO. INSP. PEP DAY	GRADING	REVEGETATION	DRAINAGE	WATER Q.	TOTAL
1.000	55927.	17481.	118114.	296535.	488056.
0.500	56232.	17552.	121663.	296535.	491983.
0.333	56535.	17623.	125175.	296535.	495868.
0.250	56834.	17694.	128648.	296535.	499711.
0.200	57129.	17764.	132084.	296535.	503513.
0.167	57422.	17833.	135483.	296535.	507274.
0.143	57712.	17902.	138846.	296535.	510995.
0.125	57998.	17971.	142174.	296535.	514678.
0.111	58282.	18038.	145466.	296535.	518321.
0.100	58562.	18106.	148724.	296535.	521927.
0.091	58840.	18172.	151948.	296535.	525496.
0.083	59114.	18239.	155139.	296535.	529027.
0.077	59386.	18304.	158297.	296535.	532522.
0.071	59655.	18369.	161422.	296535.	535982.

Table 14. Costs of Violations and Inspections
 *
 Social Costs Scaled to Maximum Durations

Option 3

NO. INSP. PER DAY	COST OF VIOL.	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	702968.	1281861.	520232.	1464596.	1.
0.500	704437.	640931.	455203.	890165.	2.
0.333	705891.	427287.	404625.	728553.	3.
0.250	707329.	320465.	364163.	663632.	4.
0.200	708753.	256372.	331057.	634068.	5.
0.167	710161.	213644.	303469.	620335.	6.
0.143	711553.	183123.	280125.	614551.	7.
0.125	712932.	160233.	260116.	613049.	8.
0.111	714297.	142429.	242775.	613951.	9.
0.100	715647.	128186.	227602.	616232.	10.
0.091	716984.	116533.	214213.	619303.	11.
0.083	718305.	106322.	202312.	622814.	12.
0.077	719615.	98605.	191664.	626555.	13.
0.071	720911.	91561.	182081.	630391.	14.

NO. INSP. PER DAY	GRADING	VEGETATION	DRAINAGE	WATER P.	TOTAL
1.000	55927.	17481.	36344.	593216.	702968.
0.500	56232.	17552.	37436.	593216.	704437.
0.333	56535.	17623.	38517.	593216.	705891.
0.250	56834.	17694.	39586.	593216.	707329.
0.200	57129.	17764.	40643.	593216.	708753.
0.167	57422.	17833.	41689.	593216.	710161.
0.143	57712.	17902.	42724.	593216.	711553.
0.125	57998.	17971.	43747.	593216.	712932.
0.111	58282.	18038.	44761.	593216.	714297.
0.100	58562.	18106.	45763.	593216.	715647.
0.091	58840.	18172.	46755.	593216.	716984.
0.083	59114.	18239.	47737.	593216.	718305.
0.077	59386.	18304.	48708.	593216.	719615.
0.071	59655.	18369.	49670.	593216.	720911.

Table 15. Costs of Violations and Inspections

Social Costs Scaled to Maximum Durations

Option 3

NO. INSP. PER DAY	COST OF VIOL.	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	784737.	1281861.	520232.	1546366.	1.
0.500	788664.	640931.	455203.	974392.	2.
0.333	792549.	427287.	404625.	815211.	3.
0.250	796392.	320465.	364163.	752695.	4.
0.200	800194.	256372.	331057.	725509.	5.
0.167	803955.	213644.	303469.	714130.	6.
0.143	807676.	183123.	280125.	710674.	7.
0.125	811359.	160233.	260116.	711475.	8.
0.111	815003.	142429.	242775.	714657.	9.
0.100	818608.	128186.	227602.	719192.	10.
0.091	822177.	116533.	214213.	724496.	11.
0.083	825707.	106822.	202312.	730216.	12.
0.077	829203.	98605.	191664.	736143.	13.
0.071	832663.	91561.	182081.	742143.	14.

NO. INSP. PER DAY	GRADING	PEVEGATION	DRAINAGE	WATER Q.	TOTAL
1.000	55927.	17481.	118114.	593216.	784737.
0.500	56232.	17552.	121663.	593216.	788664.
0.333	56535.	17623.	125175.	593216.	792549.
0.250	56834.	17694.	128648.	593216.	796392.
0.200	57129.	17764.	132084.	593216.	800194.
0.167	57422.	17833.	135483.	593216.	803955.
0.143	57712.	17902.	138846.	593216.	807676.
0.125	57998.	17971.	142174.	593216.	811359.
0.111	58282.	18038.	145466.	593216.	815003.
0.100	58562.	18106.	148724.	593216.	818608.
0.091	58840.	18172.	151948.	593216.	822177.
0.083	59114.	18239.	155139.	593216.	825707.
0.077	59386.	18304.	158297.	593216.	829203.
0.071	59655.	18369.	161422.	593216.	832663.

Table 16. Costs of Violations and Inspection

Minimum Estimates of Social Costs

Option 4

NO. INEP. PER DAY	COST OF VIOL3	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	404274.	1281861.	520232.	1165902.	1.
0.500	405732.	640931.	455203.	591460.	2.
0.333	407175.	427287.	404625.	429837.	3.
0.250	408603.	320465.	364163.	364906.	4.
0.200	410015.	256372.	331057.	335331.	5.
0.167	411413.	213644.	303469.	321588.	6.
0.143	412795.	183123.	280125.	315793.	7.
0.125	414164.	160233.	260116.	314281.	8.
0.111	415518.	142429.	242775.	315172.	9.
0.100	416858.	128186.	227602.	317443.	10.
0.091	418185.	116533.	214213.	320504.	11.
0.083	419497.	106822.	202312.	324006.	12.
0.077	420797.	98605.	191664.	327737.	13.
0.071	422083.	91561.	182081.	331563.	14.

NO. INEP. PER DAY	GRADING	VEGETATION	DRAINAGE	WATER Q.	TOTAL
1.000	53914.	17481.	36344.	296535.	404274.
0.500	54208.	17552.	37436.	296535.	405732.
0.333	54500.	17623.	38517.	296535.	407175.
0.250	54788.	17694.	39586.	296535.	408603.
0.200	55073.	17764.	40643.	296535.	410015.
0.167	55355.	17833.	41689.	296535.	411413.
0.143	55634.	17902.	42724.	296535.	412795.
0.125	55911.	17971.	43747.	296535.	414164.
0.111	56184.	18038.	44761.	296535.	415518.
0.100	56454.	18106.	45763.	296535.	416858.
0.091	56722.	18172.	46755.	296535.	418185.
0.083	56987.	18239.	47737.	296535.	419497.
0.077	57249.	18304.	48708.	296535.	420797.
0.071	57508.	18369.	49670.	296535.	422083.

case is about 3.5 days. Table 17 is our best estimate of the total costs, while Tables 18 and 19 give best and worst-case costs.

The optimal policy is also sensitive to the cost of inspection. When the cost of inspection is increased from \$28.40 to \$50.00, the optimal 7.5 days per inspection jumps to 15 days (Table 20). At an average water quality violation of three days, a \$50.00 inspection cost pushes the 3.5 days optimal inspection rate to once every 7.5 days (Table 24).

The options of man inspection cost, social cost and water quality violation lengths can be combined to give the worst-case situation in terms of costs. This occurs when water quality violations last three days (start frequently), social costs are maximum, and inspection costs are \$50.00. Under this case, the optimal inspection rate still occurs at once every 7.5 days. (See Table 26. This is also the optimal rate given in Tables 24 and 25 when water quality violations last three days and inspections cost \$50.00.)

The shortest optimal rate of inspection occurs once every 3.5 days under the options considered in this report. The other extreme of the factors which combined to give the highest inspection rate, will give the lowest inspection rate. This occurs if water quality violations last seven days, social costs are at a minimum, and inspection costs \$50.00. Under these options, inspections are less attractive because

- water quality violations last longer - fewer inspections are necessary
- other violations are less costly
- inspections are more costly.

This maximum optimal frequency rate occurred at once every 16.5 days (Table 22). This is not much greater than the 15 day rate of Table 20.

Table 17. Costs of Violations and Inspections

If Water Quality Violations Last Three Days

Option 1

NO. INSP. PER DAY	COST OF VIOL'S	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	941320.	1281861.	1133874.	1089306.	1.
0.500	943615.	640931.	850406.	734140.	2.
0.333	945885.	427287.	680325.	692648.	3.
0.250	948132.	320465.	566937.	701659.	4.
0.200	950353.	256372.	485946.	720779.	5.
0.167	952553.	213644.	425203.	740993.	6.
0.143	954728.	183123.	377958.	759892.	7.
0.125	956880.	160233.	340162.	776950.	8.
0.111	959011.	142429.	309238.	792201.	9.
0.100	961118.	128186.	283468.	805835.	10.
0.091	963204.	116533.	261663.	818074.	11.
0.083	965209.	106822.	242973.	829118.	12.
0.077	967313.	98605.	226775.	839142.	13.
0.071	969336.	91561.	212601.	848296.	14.

NO. INSP. PER DAY	GRADING	REVEGETATION	DRAINAGE	WATER Q.	TOTAL
1.000	53914.	17481.	64182.	805746.	941321.
0.500	54208.	17552.	66111.	805745.	943616.
0.333	54500.	17623.	68019.	805745.	945886.
0.250	54788.	17694.	69906.	805745.	948133.
0.200	55073.	17764.	71773.	805745.	950355.
0.167	55355.	17833.	73620.	805745.	952554.
0.143	55634.	17902.	75448.	805745.	954729.
0.125	55911.	17971.	77256.	805745.	956881.
0.111	56184.	18038.	79045.	805745.	959012.
0.100	56454.	18106.	80815.	805745.	961120.
0.091	56722.	18172.	82567.	805745.	963206.
0.083	56987.	18239.	84301.	805745.	965270.
0.077	57249.	18304.	86017.	805745.	967314.
0.071	57508.	18369.	87715.	805745.	969337.

Table 18. Costs of Violations and Inspections

If Water Quality Violations Last Three Days

"Best-Case" Option 4

NO. INCP. PER DAY	COST OF VIOL.	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	799654.	1281861.	1133874.	947640.	1.
0.500	801112.	640931.	850406.	591636.	2.
0.333	802555.	427287.	680325.	549517.	3.
0.250	803983.	320465.	566937.	557510.	4.
0.200	805396.	256372.	485946.	575821.	5.
0.167	806793.	213644.	425203.	595233.	6.
0.143	808176.	183123.	377958.	613340.	7.
0.125	809544.	160233.	340162.	629614.	8.
0.111	810898.	142429.	309238.	644088.	9.
0.100	812238.	128186.	283468.	656955.	10.
0.091	813564.	116533.	261663.	668433.	11.
0.083	814877.	106822.	242973.	678725.	12.
0.077	816177.	98805.	226775.	688006.	13.
0.071	817463.	91561.	212601.	696423.	14.

NO. INCP. PER DAY	GRADING	REVEGETATION	DRAINAGE	WATER Q.	TOTAL
1.000	53914.	17481.	36344.	691916.	799654.
0.500	54208.	17552.	37436.	691915.	801112.
0.333	54500.	17623.	38517.	691915.	802555.
0.250	54788.	17694.	39586.	691915.	803983.
0.200	55073.	17764.	40643.	691916.	805396.
0.167	55355.	17833.	41689.	691916.	806793.
0.143	55634.	17902.	42724.	691916.	808176.
0.125	55911.	17971.	43747.	691915.	809544.
0.111	56184.	18038.	44761.	691915.	810898.
0.100	56454.	18106.	45763.	691915.	812238.
0.091	56722.	18172.	46755.	691915.	813564.
0.083	56987.	18239.	47737.	691915.	814877.
0.077	57249.	18304.	48708.	691916.	816177.
0.071	57508.	18369.	49670.	691916.	817463.

Table 19. Costs of Violations and Inspections

If Water Quality Violations Last Three Days

"Worst-Case" Option 5

NO. INSP. PER DAY	COST OF VIOL.	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	1575692.	1281861.	1133874.	1723678.	1.
0.500	1579618.	640931.	850406.	1370143.	2.
0.333	1583503.	427287.	680325.	1330465.	3.
0.250	1587346.	320465.	566937.	1340874.	4.
0.200	1591149.	256372.	485946.	1361574.	5.
0.167	1594910.	213644.	425203.	1383350.	6.
0.143	1598631.	183123.	377958.	1403796.	7.
0.125	1602312.	160233.	340162.	1422383.	8.
0.111	1605956.	142429.	309238.	1439147.	9.
0.100	1609562.	128186.	283468.	1454279.	10.
0.091	1613131.	116533.	261663.	1468000.	11.
0.083	1616662.	106022.	242973.	1480510.	12.
0.077	1620158.	98605.	226775.	1491987.	13.
0.071	1623618.	91561.	212601.	1502578.	14.

NO. INSP. PER DAY	GRADING	VEGETATION	DRAINAGE	WATER Q.	TOTAL
1.000	55927.	17481.	118114.	1384173.	1575693.
0.500	56232.	17552.	121663.	1384171.	1579619.
0.333	56535.	17623.	125175.	1384171.	1583504.
0.250	56834.	17694.	128648.	1384171.	1587347.
0.200	57129.	17764.	132084.	1384173.	1591150.
0.167	57422.	17833.	135483.	1384173.	1594911.
0.143	57712.	17902.	138846.	1384173.	1598633.
0.125	57998.	17971.	142174.	1384171.	1602313.
0.111	58282.	18038.	145466.	1384171.	1605957.
0.100	58562.	18106.	148724.	1384171.	1609563.
0.091	58840.	18172.	151948.	1384171.	1613131.
0.083	59114.	18239.	155139.	1384171.	1616663.
0.077	59386.	18304.	158297.	1384173.	1620159.
0.071	59655.	18369.	161422.	1384173.	1623619.

Table 20. Costs of Inspection Process If Inspection
Costs \$50 and Water Quality Violations Last Seven Days

Option 1

NO. INCP., PER DAY	COST OF VIOL.	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	480895.	2256800.	520232.	2217462.	1.
0.500	483190.	1128400.	455203.	1156386.	2.
0.333	485461.	752266.	404625.	833102.	3.
0.250	487707.	564200.	364163.	687744.	4.
0.200	489929.	451360.	331057.	610232.	5.
0.167	492128.	376133.	303469.	564791.	6.
0.143	494303.	322400.	280125.	536578.	7.
0.125	496456.	282100.	260116.	518439.	8.
0.111	498586.	250755.	242775.	506566.	9.
0.100	500694.	225680.	227602.	498772.	10.
0.091	502780.	205164.	214213.	493730.	11.
0.083	504845.	188067.	202312.	490599.	12.
0.077	506888.	173600.	191664.	488824.	13.
0.071	508911.	161200.	182081.	488030.	14.
0.067	510913.	150453.	173411.	487956.	15.
0.063	512895.	141050.	165528.	488417.	16.
0.059	514856.	132753.	158332.	489279.	17.
0.056	516800.	125378.	151734.	490443.	18.
0.053	518723.	118779.	145665.	491837.	19.
0.050	520628.	112840.	140062.	493406.	20.
0.048	522514.	107467.	134875.	495105.	21.

Table 21. Costs of Inspection Process If Inspections
Cost \$50 and Water Quality Violations Last Seven Days

Option 1

NO. INSP. PER DAY	COST OF VIOL.	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
0.143	494303.	322400.	280125.	536578.	7.
0.071	508911.	161200.	182081.	488030.	14.
0.048	522514.	107467.	134875.	495105.	21.
0.036	535212.	80600.	107107.	508705.	28.
0.029	547094.	64480.	88820.	522753.	35.
0.024	558234.	53733.	75867.	536100.	42.
0.020	568702.	46057.	66211.	548548.	49.
0.018	578556.	40300.	58736.	560119.	56.
0.016	587848.	35822.	52777.	570893.	63.
0.014	596625.	32240.	47916.	580948.	70.
0.013	604930.	29309.	43875.	590364.	77.
0.012	612798.	26867.	40462.	599201.	84.
0.011	620264.	24800.	37542.	607521.	91.
0.010	627358.	23029.	35016.	615370.	98.
0.010	634107.	21493.	32807.	622793.	105.
0.009	640536.	20150.	30861.	629824.	112.
0.008	646666.	18965.	29133.	636497.	119.
0.008	652519.	17911.	27588.	642842.	126.
0.008	658113.	16968.	26199.	648882.	133.
0.007	663463.	16120.	24943.	654640.	140.
0.007	668587.	15352.	23801.	660138.	147.
0.006	673498.	14655.	22760.	665392.	154.
0.006	678210.	14017.	21806.	670421.	161.
0.006	682733.	13433.	20929.	675238.	168.
0.006	687080.	12896.	20119.	679856.	175.
0.005	691259.	12400.	19370.	684288.	182.

Table 22. The Longest Optimal Days Between Inspections

Water Quality Violations = 7 Days

Minimum Social Costs = Option 4

Maximum Inspection Cost = \$50

NO. INSP. PER DAY	COST OF VIOL.	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	404274.	2256800.	520232.	2140841.	1.
0.500	405732.	1128400.	455203.	1078928.	2.
0.333	407175.	752266.	404625.	754816.	3.
0.250	408603.	564200.	364163.	608640.	4.
0.200	410015.	451360.	331057.	530318.	5.
0.167	411413.	376133.	303469.	484077.	6.
0.143	412795.	322400.	280125.	455070.	7.
0.125	414164.	282100.	260116.	436148.	8.
0.111	415518.	250755.	242775.	423498.	9.
0.100	416858.	225680.	227602.	414937.	10.
0.091	418185.	205164.	214213.	409135.	11.
0.083	419497.	188067.	202312.	405251.	12.
0.077	420797.	173600.	191664.	402732.	13.
0.071	422083.	161200.	182081.	401202.	14.
0.067	423356.	150453.	173411.	400399.	15.
0.063	424616.	141050.	165528.	400138.	16.
0.059	425865.	132753.	158332.	400286.	17.
0.056	427100.	125378.	151734.	400743.	18.
0.053	428323.	118779.	145665.	401437.	19.
0.050	429535.	112840.	140062.	402312.	20.
0.048	430734.	107467.	134875.	403326.	21.

Table 23. Costs of Violations and Inspections if Water
Quality Violations Last Seven Days and Inspections
Cost \$50. Maximum Social Costs - Option 5

NO. INIP. PER DAY	COST OF VIOLC	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	784737.	2256800.	520232.	2521304.	1.
0.500	788664.	1128400.	455203.	1461860.	2.
0.333	792549.	752266.	404625.	1140190.	3.
0.250	796392.	564200.	364163.	996429.	4.
0.200	800194.	451360.	331057.	920497.	5.
0.167	803955.	376133.	303469.	876619.	6.
0.143	807676.	322400.	280125.	849950.	7.
0.125	811359.	282100.	260116.	833342.	8.
0.111	815003.	250755.	242775.	822983.	9.
0.100	818608.	225680.	227602.	816686.	10.
0.091	822177.	205164.	214213.	813127.	11.
0.083	825707.	188067.	202312.	811461.	12.
0.077	829203.	173600.	191664.	811138.	13.
0.071	832663.	161200.	182081.	811781.	14.

NO. INIP. PER DAY	GRADING	PEVEGATION	DRAINAGE	WATER Q.	TOTAL
1.000	55927.	17481.	118114.	593216.	784737.
0.500	56232.	17552.	121663.	593216.	788664.
0.333	56535.	17623.	125175.	593216.	792549.
0.250	56834.	17694.	128648.	593216.	796392.
0.200	57129.	17764.	132084.	593216.	800194.
0.167	57422.	17833.	135483.	593216.	803955.
0.143	57712.	17902.	138846.	593216.	807676.
0.125	57998.	17971.	142174.	593216.	811359.
0.111	58282.	18038.	145466.	593216.	815003.
0.100	58562.	18106.	148724.	593216.	818608.
0.091	58840.	18172.	151948.	593216.	822177.
0.083	59114.	18239.	155139.	593216.	825707.
0.077	59386.	18304.	158297.	593216.	829203.
0.071	59655.	18369.	161422.	593216.	832663.

Table 24. Costs of Inspection Process If Man Inspections

Cost \$50 and Water Quality Violations Last Three Days

Option 1

NO. INSP. PER DAY	COST OF VIOL.	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	941320.	2256800.	1133874.	2064244.	1.
0.500	943615.	1128400.	850406.	1221602.	2.
0.333	945885.	752266.	680325.	1017827.	3.
0.250	948132.	564200.	566937.	945394.	4.
0.200	950353.	451360.	485946.	915767.	5.
0.167	952553.	376133.	425203.	903482.	6.
0.143	954728.	322400.	377958.	893169.	7.
0.125	956880.	282100.	340162.	898817.	8.
0.111	959011.	250755.	309238.	900527.	9.
0.100	961118.	225680.	283468.	903329.	10.
0.091	963204.	205164.	261663.	906704.	11.
0.083	965269.	188067.	242973.	910362.	12.
0.077	967313.	173600.	226775.	914137.	13.
0.071	969336.	161200.	212601.	917934.	14.
0.067	971338.	150453.	200095.	921695.	15.
0.063	973320.	141050.	188979.	925390.	16.
0.059	975282.	132753.	179033.	929002.	17.
0.056	977225.	125378.	170081.	932521.	18.
0.053	979149.	118779.	161982.	935945.	19.
0.050	981053.	112840.	154619.	939273.	20.
0.048	982939.	107467.	147897.	942508.	21.

Table 25. Costs of Violations and Inspections
If Water Quality Violations Last Three Days
and Inspections Cost \$50.

Minimum Social Costs - Option 4

NO. INCP. PEP DAY	COST OF VIOL.	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	799654.	2256800.	1133874.	1922578.	1.
0.500	801112.	1128400.	850406.	1079105.	2.
0.333	802555.	752266.	680325.	874496.	3.
0.250	803983.	564200.	566937.	801245.	4.
0.200	805396.	451360.	485946.	770809.	5.
0.167	806793.	376133.	425203.	757723.	6.
0.143	808176.	322400.	377958.	752618.	7.
0.125	809544.	282100.	340162.	751481.	8.
0.111	810898.	250755.	309238.	752414.	9.
0.100	812238.	225680.	283468.	754448.	10.
0.091	813564.	205164.	261663.	757064.	11.
0.083	814877.	188067.	242973.	759970.	12.
0.077	816177.	173600.	226775.	763001.	13.
0.071	817463.	161200.	212601.	766061.	14.

NO. INCP. PEP DAY	GRADING	REVEGETATION	DRAINAGE	WATER Q.	TOTAL
1.000	53914.	17481.	36344.	691916.	799654.
0.500	54208.	17552.	37436.	691915.	801112.
0.333	54500.	17623.	38517.	691915.	802555.
0.250	54788.	17694.	39586.	691915.	803983.
0.200	55073.	17764.	40643.	691916.	805396.
0.167	55355.	17833.	41689.	691916.	806793.
0.143	55634.	17902.	42724.	691916.	808176.
0.125	55911.	17971.	43747.	691915.	809544.
0.111	56184.	18038.	44761.	691915.	810898.
0.100	56454.	18106.	45763.	691915.	812238.
0.091	56722.	18172.	46755.	691915.	813564.
0.083	56987.	18239.	47737.	691915.	814877.
0.077	57249.	18304.	48708.	691916.	816177.
0.071	57508.	18369.	49670.	691916.	817463.

Table 26. The Most Expensive Assumptions

Water Quality Violations = 3 Days

Maximum Social Costs = Option 5

Maximum Inspection Cost = \$50

NO. INSP. PER DAY	COST OF VIOL.	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	1575692.	2256800.	1133874.	2698617.	1.
0.500	1579618.	1128400.	850406.	1857612.	2.
0.333	1583503.	752266.	680325.	1655445.	3.
0.250	1587346.	564200.	566937.	1584609.	4.
0.200	1591149.	451360.	485946.	1556562.	5.
0.167	1594910.	376133.	425203.	1545839.	6.
0.143	1598631.	322400.	377958.	1543072.	7.
0.125	1602312.	282100.	340162.	1544250.	8.
0.111	1605956.	250755.	309238.	1547473.	9.
0.100	1609562.	225680.	283468.	1551773.	10.
0.091	1613131.	205164.	261663.	1556631.	11.
0.083	1616662.	188067.	242973.	1561755.	12.
0.077	1620158.	173600.	226775.	1566982.	13.
0.071	1623618.	161200.	212601.	1572216.	14.
0.067	1627042.	150453.	200095.	1577400.	15.
0.063	1630431.	141050.	188979.	1582502.	16.
0.059	1633787.	132753.	179033.	1587507.	17.
0.056	1637110.	125378.	170081.	1592406.	18.
0.053	1640399.	118779.	161982.	1597196.	19.
0.050	1643654.	112840.	154619.	1601875.	20.
0.048	1646880.	107467.	147897.	1606449.	21.

Summarizing, Table 27 compares the minimum inspection process costs with the costs under the 1974 inspection rate and the worst-case yearly rate. These costs depend on the social costs, inspection costs, and frequencies of violations. The least savings in using the optimal rate occurs under the assumption that water quality violations last seven days. As a "best" optimal plan, MATHEMATICA recommends the social cost option 1, water quality violations of length 3 days, with man inspection costs of \$50.00 to give an optimal rate of inspection of 7.5 days with a total estimated savings over the 1974 inspection rate (once in every 55 days) of \$1,048,448 - \$898,817 = \$119,631.

The total cost of violations under the optimal rate can be found in Table 17. These costs are

Grading	\$ 55,911
Revegetation	17,971
Drainage	77,256
Water Quality	<u>805,745</u>
Total	\$956,881

The total fines collected for water quality violations at the optimal inspection rate is estimated to be \$340,162.

It is likely that water quality violations would decrease at a 7.5 day inspection rate. As a result, the total of fines collected would also decrease. However, because the total fines collected are less than the cost of water quality violations, a decrease in water quality violations would lower the estimated cost of \$898,817. The estimated savings would thus be greater than \$119,631 if water quality violations decreased with increasing inspection rates.

Table 27. Comparison of Optimal Inspection Costs
With Yearly and 1974 Inspection Rates

Social Cost Option	Water Quality Duration	Cost of Manned Inspection	Optimal Time Between Inspections (days)	Inspections at 1974 Rate C_{AVE}	Inspections at Yearly Rate C_{MAX}	Inspections at Optimal Rate C_{OPT}	Percent of Costs of 1974 Rate $100 C_{OPT}/C_{AVE}$	Maximum Savings $C_{AVE}-C_{OPT}$
1	7	\$28.40	7.5	\$ 531,695	\$ 905,288	\$ 396,572	74.6	\$135,393
2	7	28.40	7.5	615,393	1,211,093	413,993	67.3	201,400
3	7	28.40	8.0	727,850	969,269	613,049	84.3	114,801
4	7	28.40	8.0	428,698	675,562	314,281	73.3	114,417
5	7	28.40	7.5	972,075	1,507,774	710,674	73.1	261,401
1	3	\$28.40	3.5	\$1,000,625	\$1,365,717	\$ 692,848	69.2	\$307,777
4	3	28.40	3.5	824,078	1,070,942	549,517		274,561
5	3	28.40	3.5	1,703,031	2,298,731	1,330,465		372,566
1	7	\$50.00	15.0	\$ 558,023	\$ 905,288	\$ 487,956	48.8	\$ 70,067
4	7	50.00	16.0	465,282	675,562	400,138	86.0	65,144
5	7	50.00	13.0	929,899	1,507,774	811,138		118,761
1	3	\$50.00	7.5	\$1,018,448	\$1,365,717	\$ 898,817	88.2	\$119,631
4	3	50.00	8.0	841,903	1,070,942	751,481		90,422
5	3	50.00	7.5	1,720,856	2,298,731	1,543,072		177,784

4. Optimal Ground Inspection Under Adjusted 1971-74 Inspection Rates

Estimates of the frequency of occurrence of violations depend on the frequency of inspections made during 1971-74. After the analysis of the previous section was presented to the Kentucky Division of Reclamation, MATHEMATICA was given new information on this inspection rate. Prior to 1975, inspectors were not obligated to file an inspection report for each inspection. As a result, the total number of inspections is significantly higher than the value 2760 derived from the inspection reports. Claude Downing has records which show an average of 244 inspections per month, during fiscal year 1975. A subjective estimate of the rate of inspections prior to 1975 is 85 percent of this value. Thus, an estimate of the true rate of inspections per permit per week in 1974 is

$$p_D = \frac{244 \times .85 \times 12}{128 \times 52} = 0.373918$$

This value gives an average revisit time per permit of 18.72 days; a value significantly less than the 55 days used in Section 3.

While this adjusted value of p_D does change the estimates of violation frequencies, (Table 28) the most significant effect, which considerably lengthens the optimal revisit time, is the rate of fines for water quality violations. The adjusted value of p_D implies the average fine collected per water quality violation is only one-third of the original estimated average fine.

Fines are only one benefit of inspections. As noted in the previous section, it can be expected that water quality violations will decrease with increasing inspections. If the ratio of fines is to be considerably reduced, the model should be adjusted to allow for decreasing

Table 28. Estimated Frequencies for Detection Model
When 1971-74 Inspection Rate is Once Every 19 Days

Parameter	Grading (per week)	Revegetation (per week)	Drainage Control (per week)	Water Quality (per week)
L_1	26.00	34.67	26.00	7.00
L	13.79	18.13	5.33	5.87
L_2	13.00	17.33	4.00	3.00
r_1	0.9615	0.9712	0.9615	0.8571
r	0.9275	0.9448	0.8124	0.8296
r_2	0.9231	0.9423	0.7500	0.6667
p_1	0.1309	0.00967	1.2683	0.0101
p	0.0504	0.00834	0.0466	0.00996
f_1	0.7728	0.2510	0.9706	0.0659
f	0.4098	0.1313	0.1990	0.0552
s	0.0297	0.00724	0.0373	0.00941

water quality violations. Because the optimal inspection policy is much more sensitive to any assumptions about fines, costs, and frequencies of the relatively short water qualities than it is sensitive to the parameters of the other three violation types, correct modelling of water quality violations is important. The following adjustments have been made on the parameters for water quality violations:

<u>Original Model</u>	<u>Adjusted Model</u>
Water quality violations last a fixed average length independent of the inspection frequency. Two estimated lengths are 3 days and 7 days.	Water quality violations last an average of 7 days if no inspections are made; the violations last 3 days after detection.
Fines for water quality violations are collected at a rate such that if inspections are made every 55 days, an average of 12 fines of \$5000 each are collected.	Fines for water quality violations are collected at a rate such that if inspections are made every 19 days, an average of 12 fines of \$5000 each are collected.

The violation parameters L_1 , L_2 , and f used to estimate the remaining parameters remain unchanged. The remaining parameters depend on p_D . The adjusted parameters are given in Table 28.

The same methodology as used in Section 3 was used to determine the optimal ground inspection frequency under three social cost options. Option 4 and 5, identical to options 4 and 5 of Table 10, are derived by scaling the total estimated social costs by the shortest and longest durations, L_2 and L_1 , respectively, to obtain costs per week. Option 6 uses the average duration L under the adjusted inspection rate. Because L is approximately the minimum duration L_2 for three of the violations, only water quality costs differ significantly from option 4.

Table 29. Social Cost Options for Sensitivity Analysis
Under Adjusted Inspection Rates

Option	Cost/Week of Violation			
	Grading	Revegetation	Drainage Control	Water Quality
Option 4	24.64	24.04	60.67	833.13
Option 5	25.56	24.04	197.17	1666.67
Option 6	24.64	24.04	60.67	997.73

Social costs are low under either options 4 or 6. Fines are collected at a much lower rate than assumed in Section 3. Yet, the optimal inspection rates are about the same as in Section 3. This occurs because, unlike Section 3, there are two benefits accrued by detecting poor water quality. Detections increase fines and shorten the length. Under option 4 or 6, the optimal rate is about one inspection per permit every ten days when ground inspections cost \$28.40. When inspections cost \$50, the optimal rate is approximately the 18 day rate actually conducted during the 1971-74 period.

The \$28.40 cost of inspection has been calculated by assuming ten inspectors make 400 inspections per month. If 124 permitted areas are to be inspected, this is equivalent to ten inspectors inspecting a permit area once every 9.4 days.

The \$50.00 cost of inspection is the approximate cost if ten inspectors make 207 inspections per month. At this inspection rate, 124 permitted areas are inspected every 18 days.

Thus, very surprisingly, under our cost model, ten inspectors is optimal over a broad range of estimated costs per inspection. The invariance of the optimal number of ten inspectors occurs because the optimal average days between ground inspections is approximately proportional to inspection costs. For a fixed number of inspectors, the cost per inspection is indeed proportional to the number of days between inspections. Thus, the optimal number of inspectors is fixed.

If social cost option 6 is used, violations are more costly and, hence, inspections are more beneficial. At the \$28.40 inspection cost, the optimal inspection rate is once per six days. The solution to the equation

$$\frac{x \text{ inspectors}}{10 \text{ inspectors}} = \frac{9.4 \text{ days}}{6 \text{ days}}$$

is 16 inspectors per 124 permits. When inspections cost \$50 the optimal inspection rate is once per 10.5 days. The optimal number of inspectors at the \$50 rate is also 16.

In this section, we have kept the optimal inspection rate high by using a model which assumes water quality violation frequencies decrease with increasing inspection rates. In Section 3, the optimal inspection rate is high because we have used a high rate of fines per inspection. Neither one of these cases need be true. However, it is certain that if sufficiently high fines are collected, water quality violation frequencies will decrease both in average duration and in frequency of starts. When start frequencies are lowered, inspection rates can be lowered. The development of an optimal rate of fines as well as optimal inspection

policy using dynamic start frequencies depending on these rates is very important, but beyond the scope of this report.

Table 30. Comparison of Optimal Adjusted Costs
With Yearly and 1974 Adjusted Costs

Social Cost Option	Cost of Man Inspections	Optimal Time Between Inspections (days)	Inspections at 1974 Rate C_{AVE}	Inspections at Yearly Rate C_{MAX}	Inspections at Optimal Rate C_{opt}	Percent of Costs of 1974 Rate $100 C_{opt}/C_{AVE}$	Maximum Savings $C_{AVE} - C_{opt}$
4	\$28.40	10.5	\$479,547	\$895,163	\$462,647	96.5	16,900
5	28.40	6.0	974,268	2,107,939	872,011	89.5	102,257
6	28.40	9.5	536,793	968,047	513,672	95.7	23,121
4	\$50.00	19	531,629	\$895,163	\$531,608	100.0	21
5	50.00	10.5	1,026,350	2,107,939	993,485	96.8	32,865
6	50.00	18	588,875	968,047	588,715	100.0	160

Table 31. Costs of Violations and Inspections Under Adjusted Rates

Option 4.

NO. INSP. PER DAY	GRADING	REVEGATION	DRAINAGE	WATER Q.	TOTAL
1.000	61395.	19455.	58412.	151620.	290882.
0.500	61730.	19535.	60168.	176890.	318323.
0.333	62062.	19614.	61904.	196544.	340125.
0.250	62390.	19693.	63622.	212268.	357973.
0.200	62715.	19771.	65321.	225132.	372940.
0.167	63036.	19848.	67002.	235853.	385740.
0.143	63354.	19925.	68666.	244924.	396869.
0.125	63669.	20001.	70311.	252699.	406680.
0.111	63980.	20076.	71939.	259438.	415433.
0.100	64288.	20151.	73551.	265334.	423324.
0.091	64592.	20225.	75145.	270537.	430500.
0.083	64894.	20299.	76723.	275162.	437078.
0.077	65192.	20372.	78285.	279299.	443148.
0.071	65488.	20445.	79830.	283023.	448786.

FOR VIOLS.

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IF OLD COSTS

NO. INSP. PER DAY	COST OF VIOLS	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	290882.	1281861.	241200.	4331543.	1.
0.500	318323.	640931.	187600.	771653.	2.
0.333	340125.	427287.	159283.	608129.	3.
0.250	357973.	320465.	140700.	537738.	4.
0.200	372940.	256372.	127084.	502228.	5.
0.167	385740.	213644.	116441.	482942.	6.
0.143	396869.	183123.	107770.	472222.	7.
0.125	406680.	160233.	100500.	466413.	8.
0.111	415433.	142429.	94276.	463586.	9.
0.100	423324.	128186.	88863.	462647.	10.
0.091	430500.	116533.	84096.	462936.	11.
0.083	437078.	106822.	79857.	464043.	12.
0.077	443148.	98605.	76054.	465699.	13.
0.071	448786.	91561.	72619.	467728.	14.

Table 32. Cost of Violations and Inspections Under Adjusted Rates

Option 5.

NO. INCP. PER DAY	GRADING	REVEGETATION	DRAINAGE	WATER P.	TOTAL
1.000	63687.	19455.	189833.	303314.	576290.
0.500	64035.	19535.	195538.	353866.	632974.
0.333	64379.	19614.	201182.	393185.	678360.
0.250	64720.	19693.	206764.	424640.	715816.
0.200	65057.	19771.	212286.	450376.	747489.
0.167	65390.	19848.	217750.	471822.	774809.
0.143	65720.	19925.	223155.	489969.	798768.
0.125	66046.	20001.	228503.	505523.	820073.
0.111	66369.	20076.	233794.	519004.	839243.
0.100	66688.	20151.	239031.	530799.	856669.
0.091	67004.	20225.	244212.	541207.	872649.
0.083	67317.	20299.	249340.	550459.	887415.
0.077	67626.	20372.	254415.	558736.	901150.
0.071	67933.	20445.	259439.	566186.	914002.

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TYPE 0 IF OLD COST
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NO. INSP. PER DAY	COST OF VIOLS	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	576290.	1281861.	241200.	1616950.	1.
0.500	632974.	640931.	187600.	1086304.	2.
0.333	678360.	427287.	159283.	946364.	3.
0.250	715816.	320465.	140700.	895581.	4.
0.200	747489.	256372.	127084.	876777.	5.
0.167	774809.	213644.	116441.	872011.	6.
0.143	798768.	183123.	107770.	874120.	7.
0.125	820073.	160233.	100500.	879805.	8.
0.111	839243.	142429.	94276.	887396.	9.
0.100	856669.	128186.	88863.	895992.	10.
0.091	872649.	116533.	84096.	905084.	11.
0.083	887415.	106822.	79857.	914379.	12.
0.077	901150.	98605.	76054.	923700.	13.
0.071	914002.	91561.	72619.	932944.	14.

Table 33. Cost of Violations and Inspections Under Adjusted Rates

Option 6.

NO. INSP. PER DAY	GRADING	VEGETATION	DRAINAGE	WATER Q.	TOTAL
1.000	61395.	19455.	58412.	180891.	320153.
0.500	61730.	19535.	60168.	211039.	352472.
0.333	62062.	19614.	61904.	234488.	378069.
0.250	62390.	19693.	63622.	253247.	398952.
0.200	62715.	19771.	65321.	268595.	416402.
0.167	63036.	19848.	67002.	281385.	431272.
0.143	63354.	19925.	68666.	292208.	444152.
0.125	63669.	20001.	70311.	301484.	455465.
0.111	63980.	20076.	71939.	309524.	465519.
0.100	64282.	20151.	73551.	316558.	474548.
0.091	64592.	20225.	75145.	322766.	482728.
0.083	64894.	20299.	76723.	328283.	490199.
0.077	65192.	20372.	78285.	333220.	497069.
0.071	65488.	20445.	79830.	337662.	503425.

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TYPE 0 FOR VIOL'S.

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TYPE 0 IF OLD COSTS

NO. INSP. PER DAY	COST OF VIOL'S	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	320153.	1281861.	241200.	1360814.	1.
0.500	352472.	640931.	187600.	805803.	2.
0.333	378069.	427287.	159283.	646073.	3.
0.250	398952.	320465.	140700.	578717.	4.
0.200	416402.	256372.	127084.	545691.	5.
0.167	431272.	213644.	116441.	528474.	6.
0.143	444152.	183123.	107770.	519505.	7.
0.125	455465.	160233.	100500.	515197.	8.
0.111	465519.	142429.	94276.	513672.	9.
0.100	474548.	128186.	88863.	513871.	10.
0.091	482728.	116533.	84096.	515165.	11.
0.083	490199.	106822.	79857.	517164.	12.
0.077	497069.	98605.	76054.	519619.	13.
0.071	503425.	91561.	72619.	522367.	14.

Table 34. Costs of Violations and Inspections Under Adjusted Rates

If Man Inspections Cost \$50.

Option 4.

NO. INSP. PER DAY	COST OF VIOLS	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	290882.	2256800.	241200.	2306481.	1.
0.500	318323.	1128400.	187600.	1259122.	2.
0.333	340125.	752266.	159283.	933108.	3.
0.250	357973.	564200.	140700.	781473.	4.
0.200	372940.	451360.	127084.	697215.	5.
0.167	385740.	376133.	116441.	645431.	6.
0.143	396869.	322400.	107770.	611498.	7.
0.125	406680.	282100.	100500.	588280.	8.
0.111	415433.	250755.	94276.	571913.	9.
0.100	423324.	225680.	88863.	560140.	10.
0.091	430500.	205164.	84096.	551567.	11.
0.083	437078.	188067.	79857.	545287.	12.
0.077	443148.	173600.	76054.	540694.	13.
0.071	448786.	161200.	72619.	537367.	14.
0.067	454049.	150453.	69498.	535004.	15.
0.063	458987.	141050.	66647.	533390.	16.
0.059	463641.	132753.	64031.	532363.	17.
0.056	468042.	125378.	61620.	531799.	18.
0.053	472220.	118779.	59391.	531608.	19.
0.050	476199.	112840.	57322.	531716.	20.
0.048	479999.	107467.	55397.	532069.	21.

Table 35. Cost of Violations and Inspections Under Adjusted Rates

If Ground Inspections Cost \$50.

Option 6.

NO. INEP. PEP DAY	COST OF VIOLG	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	320153.	2256800.	241200.	2335753.	1.
0.500	352472.	1128400.	187600.	1293272.	2.
0.333	378069.	752266.	159283.	971052.	3.
0.250	398952.	564200.	140700.	822452.	4.
0.200	416402.	451360.	127084.	740678.	5.
0.167	431272.	376133.	116441.	690963.	6.
0.143	444152.	322400.	107770.	658782.	7.
0.125	455465.	282100.	100500.	637065.	8.
0.111	465519.	250755.	94276.	621999.	9.
0.100	474548.	225680.	88863.	611365.	10.
0.091	482728.	205164.	84096.	603795.	11.
0.083	490199.	188067.	79857.	598409.	12.
0.077	497069.	173600.	76054.	594614.	13.
0.071	503425.	161200.	72619.	592006.	14.
0.067	509339.	150453.	69498.	590294.	15.
0.063	514868.	141050.	66647.	589271.	16.
0.059	520061.	132753.	64031.	588783.	17.
0.056	524957.	125378.	61620.	588715.	18.
0.053	529591.	118779.	59391.	588979.	19.
0.050	533990.	112840.	57322.	589508.	20.
0.048	538179.	107467.	55397.	590249.	21.

Table 36. Cost of Violations and Inspections Under Adjusted Rates

If Ground Inspections Cost \$50.

Option 5.

NO. INSP. PER DAY	COST OF VIOL.	COST OF INSPECTION	FINES	TOTAL	DAYS BETWEEN INSPECTIONS
1.000	576290.	2256800.	241200.	2591889.	1.
0.500	632974.	1128400.	187600.	1573774.	2.
0.333	678360.	752266.	159283.	1271342.	3.
0.250	715816.	564200.	140700.	1139315.	4.
0.200	747489.	451360.	127084.	1071764.	5.
0.167	774809.	376133.	116441.	1034500.	6.
0.143	798768.	322400.	107770.	1013297.	7.
0.125	820073.	282100.	100590.	1001672.	8.
0.111	839243.	250755.	94276.	995722.	9.
0.100	856662.	225680.	88863.	993485.	10.
0.091	872649.	205164.	84096.	993715.	11.
0.083	887415.	188067.	79857.	995624.	12.
0.077	901150.	173600.	76054.	998695.	13.
0.071	914002.	161200.	72619.	1002582.	14.
0.067	926090.	150453.	69498.	1007044.	15.
0.063	937510.	141050.	66647.	1011912.	16.
0.059	948344.	132753.	64031.	1017065.	17.
0.056	958660.	125378.	61620.	1022417.	18.
0.053	968514.	118779.	59391.	1027901.	19.
0.050	977953.	112840.	57322.	1033470.	20.
0.048	987021.	107467.	55397.	1039090.	21.

VI. AERIAL AND SATELLITE POLICIES

1. Satellite and Aircraft Detection Parameters

a. Satellite Parameters

The benefits of aerial or satellite inspection policies depend critically on the costs of inspection and on the ability to correctly classify mining violations under such policies. Several options are available for satellite inspection. Among these are:

- Black and white prints for each channel (Appendix D)
- Color coded ozalids for each channel
- Graymaps for each channel (Appendix D)
- Graymaps for channel ratios (Appendix D)
- Recognition maps (Appendix D)
- Inksquirts

Of the above, recognition maps provide the least misclassification errors. This is necessarily true because recognition maps are formulated from ground truth data. Through a cluster analysis of the electronic data in areas where ground truth is known, signatures are developed for each of the categories of interest (Appendix C). These signature are computer decision rules for classifying the vector of channel voltages for each pixel.

After this report through Section 3 of Chapter V was completed, an analysis of the LANDSAT data sets developed by ERIM was conducted in Madisonville. The man inspection policy costs developed in Section 3 of Chapter V were also presented at this meeting. MATHEMATICA was given a new estimate of the true inspection rate for 1971-74 which is considerably higher than the rate of inspections reported during this period. Adjusted rates and corresponding adjusted cost estimates of man

inspection policies have been given in Section 4, Chapter V. In this Chapter, we will give two analyses for aerial and satellite policies. One analysis, with parameters defined by the inspection reports only, can be compared to the optimal ground inspection only policy of Section 3, Chapter V. This analysis is given in the next section. The other analysis, given in Section 3, uses the adjusted rates.

It was determined at Madisonville, that only the recognition map was of use in detecting coal mining violations. The recognition map was excellent for distinguishing between greater than 70% and less than 70% revegetation. None of the other violation types were detectable. While there were several cases where large areas were misclassified, such as the identification of bare agricultural areas as strip mines, the primary reason a zero probability must be assigned to the detection of violations other than revegetation is low resolution. In Chapter VII, we recommend a minimal resolution for the detection of other violations.

ERIM has provided the following estimates of costs of each data set developed by ERIM for this project:

COLOR CODED OZALIDS

Labor (Photo)	\$ 145.00
Mtls (Photo)	20.00
	\$ 165.00

GRAYMAPS OF RATIOS AND SINGLE CHANNELS

Labor (Wagner, Rebel, Thomson)	\$1,512.00
7094 and 1401 Computer	1,196.00
470 Computer	80.00
Tapes	138.00
Mailing Costs	24.00
	\$2,950.00

RECOGNITION MAP PROCESSING

Labor (Wagner, Rebel, Colwell, Thomson)	\$2,936.00
7094 and 1401 Computer	1,698.00
470 Computer	80.00
Tapes	138.00
Mailing Costs	<u>24.00</u>
	\$4,876.00

As an estimate of the cost of recognition map processing, we will use the fixed cost of \$2000. This estimate is the sum of \$350 for labor (six man-days at \$15,000 including overhead) and \$1,650 for computer costs. This figure is speculative. Factors considered were

- The computer is state-owned
- The computer is possibly more efficient than the 7094 or 1401
- The computer algorithms could be simplified
- The costs are for a 4300 sq. mile coverage. The products developed by ERIM have a 190 sq. mile coverage.
- A portion of ERIM's costs are initial costs which would not be duplicated in later processing costs.

The misclassification probabilities for recognition maps are estimated by the following:

- For all four violations,
$$P(\text{violation is "detected"} | \text{violation does not exist}) = 0.$$
- For revegetation violations only,
$$P(\text{revegetation violation not detected} | \text{revegetation violation exists}) = 0.$$
- For grading, drainage control and water quality violations,
$$P(\text{violation is not "detected"} | \text{violation exists}) = 1.$$

b. Low Altitude Parameters

Birney R. Fish, the Principal Investigator has estimated the costs of low altitude photography for photographing and interpreting the entire active mining area of western Kentucky. The calculations are as follows:

- Active Mining Area = 4300 square miles. Each roll of film covers 170 linear miles.
- To cover an area, the center to center flight lines must be 3.386 miles.
- Allowing for over-lap, 9 rolls of film are required.
- These 9 rolls of film require 1530 data miles of flight.
- At 90¢ per data mile, 1530 data miles cost \$1377.
- The fixed cost for two hours flight to Madisonville is \$240.
- Total cost of aircraft \$1617.

The costs for film and processing are as follows:

Film	Cost per Roll	Processing Costs	Shipping	Total Cost Per Roll
Color IR	\$341.50	\$123.75	\$34.00	\$499.25
Color Transparency	229.70	123.75	34.00	387.45
B&W Print	63.45	276.50	-	339.95
B&W Positive Transparency	63.45	291.05	34.00	388.00
B&W IR	118.35	353.55	34.00	505.90

Because of the expense of processing, Color IR and Color Transparencies are preferred to B&W IR and B&W Transparencies. The total costs for nine developed rolls of film plus aircraft are:

Color IR = \$6110

Color Transparency = 5104

B&W print = 4677

These costs are relevant when low altitude photography is used as a surrogate for satellite photography. In this case, the entire active coal mining area is photographed. If only the permitted areas are photographed, the inspection costs can be considerably reduced. The total areas of permitted strip mining regions during 1971-75 averaged less than 20 square miles per year. The acreage of active mines at any time is less than this value.

Table 36A. Yearly Acreage of Permitted Strip Mining
(1971-75)

Year	Number Mines	Number Permits	Total Acreage	Square Miles
1971	85	140	6104	9.54
1972	71	103	7935	12.40
1973	55	77	10272	16.05
1974	90	128	12765	19.95
1975	--	176	10361	16.19

Thus, at most one roll of film is necessary for photographing strip mining permits. The unit cost per permit is estimated to be \$12 (13.33 miles between mines at 90¢ per mile). Thus, for the s-a-m model, low

altitude costs for color IR are estimated to be

$$\text{Color IR} = (240 + 499.25) + 12 n$$

where n = number of permits inspected. When 124 permits are inspected, the total costs for color IR are

$$\text{Color IR} = \$2227.25.$$

In the cost analysis, we have used the costs of permit inspections for low altitude photography. In the next chapter, we show that frequent coverage of the entire 4300 square mile mining area is not justified.

Low altitude photography is excellent for detecting coal mining violations. With color IR, different shades of color for water, defining physical and chemical water quality, can be seen. The precision of estimating water acidity, iron content, or turbidity by color IR is not known. It is possible that chemically treated mine drainage can be distinguished from non-treated drainage. Certainly, the condition of silt structures is detectable. Thus, we have assumed no misclassification errors for mining violations under low altitude color IR.

b. High Altitude Costs

Mark Hurd Aerial Survey of Minneapolis uses a Lear Jet with photography scaled at 1:80,000. This is larger than the scale from NASA overflights of 1:130,000. The cost per linear mile of photography is \$20 to \$30 depending on the type of film, and more important, the frequency with which photography is to be taken. For the active mining area of 4,300 miles, it is estimated that 700 linear miles are

needed. The total cost is in the range \$14,000 to \$21,000.

A comparison between the low and high altitude costs shows that low altitude aircraft photography should be preferred for covering the entire active mine area. The savings in developed film costs is at least \$8,000.

The scale of low altitude photography is 1:24,000. To cover the same area as 1:80,000 film, $(3.33)^2$ or 11.1 low altitude photos must be interpreted for every high altitude photo. But at a savings of \$8,000, expensive methods of interpretation can be used for low aircraft photography and still be cost effective.

Because the option of high altitude photography is not cost effective, it will be dropped from further consideration.

2. Computer Simulations

Tables 31-41C are computer printouts of simulated satellite and aircraft inspection policies. The simulation period used was 4,000 weeks. A constant "seed" was used in each simulation run for generating the violations. This gives identical violation frequencies for each run. Thus, the simulations can legitimately be compared for cost effectiveness even though the simulated violation frequencies differ from the theoretical frequencies because of random error. The simulated period of 4,000 weeks was necessary to obtain accurate estimates of the low transition probabilities. For example, only 21 runs of revegetation violations averaging length of 42.95 (theoretical value is 34.67) weeks were observed during this period. Because violations were simulated at a single permit area, the equivalent simulation of violations for 124 permitted areas is $4,000/124 = 32$ weeks. The boundary effects of initializing and ending the simulation make a single-permit area, 4,000-week simulation more accurate than a 124-permit, 32-week simulation.

The fraction of satellite accesses over Kentucky which were 70% or greater cloud-free was precisely .30 over a four year period. The average revisit time for satellites if accesses occur once every 9 days and photography is made under 70% or greater cloud-free coverage is 30 days. Erroneous computer input, however, for Tables 37-41C resulted in an average revisit time of 9 days. Thus, cloud-cover is ignored.

The social costs used in the model are defined by option 1, in Table 10. A comparison of the total costs defined by the simulations shows that ground inspections are much less costly.

Over and above questions of cloud cover, there are two important reasons why satellites are not cost effective at this time. One is the high rate of misclassification of violations. The other is the large delay between a satellite pass and a manned inspection.

Although airplane inspections are less costly per unit inspection than manned inspections, a strategy employing only manned inspection is still the least costly. At the highest possible rate of inspection there are two cases:

- aircraft inspections are made once per week and manned inspections are made during the same week when necessary.
- manned inspections are made once per week.

The total of social costs and fines are identical in the two cases. Only 2,700 manned inspections per year are required in the first case; 6,448 manned inspections per year are required in the second case. But the cost of 52 airplane inspections plus 2,700 manned inspections is greater than 6,448 manned inspections.

More simulations should be made to estimate the future cost of satellite or aerial inspection under more optimistic assumption for satellites. This is done in Section 3 using the adjusted violation model defined in Section 4, Chapter V.

Table 37

ASSUMPTIONS: 9. DAYS BETWEEN SAT. PASSES
56. DAYS TO AIRPLANE
7. DAYS TO MAN INSPECTION

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF PUNS	AVERAGE LENGTH OF PUN:	NUMBER DETECTED	PPIDP AVERAGE LENGTH
GRADING	1.08	20.76	0.48	23.13
REVEGETATION	0.27	23.24	0.66	42.95
DRAINAGE	0.77	23.27	0.23	27.98
WATER Q.	2.98	1.00	0.04	1.00

YEARLY CLOUD-FREE SAT. PASSES = 39.6 AT COST OF \$ 79,200.

YEARLY 39.1 AIRPLANE PASSES INSPECTING 174.1 MINES AT COST OF \$ 30994.

YEARLY 112.8 MAN INSPECTIONS AT COST OF \$ 3205.

YEARLY SOCIAL COST OF VIOL IS \$ 682621.

TOTAL OF FINES IS \$ 6370.

TOTAL YEARLY COST IS \$ 789650.

Table 38

ASSUMPTIONS: 9. DAYS BETWEEN SAT. PASSES
 NO AIRPLANE
 56. DAYS TO MAN INSPECTION

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF PUNC	AVERAGE LENGTH OF PUNC	NUMBER DETECTED	PRIOR AVERAGE LENGTH
GRADING	1.08	21.49	0.32	23.13
REVEGETATION	0.27	23.29	0.65	42.95
DRAINAGE	0.77	23.49	0.19	27.98
WATER C.	2.98	1.00	0.01	1.00

YEARLY CLOUD-FREE SAT. PASSES = 39.4 AT COST OF \$ 78800.

YEARLY 0.0 AIRPLANE PASSES INSPECTING 0.0 MINES AT COST OF \$ 0.

YEARLY 112.8 MAN INSPECTIONS AT COST OF \$ 3205.

YEARLY SOCIAL COST OF VIOL IS \$ 687329.

TOTAL OF FINES IS \$ 2123.

TOTAL YEARLY COST IS \$ 767210.

Table 39

ASSUMPTIONS: 18. DAYS BETWEEN SAT. PASSES
NO AIRPLANE
56. DAYS TO MAN INSPECTION

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF PUNS	AVERAGE LENGTH OF PUNS	NUMBER DETECTED	PRODP AVERAGE LENGTH
GRADING	1.08	21.20	0.26	23.13
REVEGETATION	0.27	24.95	0.70	42.95
DRAINAGE	0.77	24.03	0.16	27.98
WATER O.	2.98	1.00	0.02	1.00

YEARLY CLOUD-FREE SAT. PASSES = 22.8 AT COST OF \$ 45600.

YEARLY AIRPLANE PASSES INSPECTING MINES AT COST OF \$ 0.

YEARLY 109.6 MAN INSPECTIONS AT COST OF \$ 3113.

YEARLY SOCIAL COST OF VIOL IS \$ 693258.

TOTAL OF FINES IS \$ 2593.

TOTAL YEARLY COST IS \$ 739379.

Table 40

ASSUMPTIONS: NO SATELLITE
NO AIRPLANE
56. DAYS TO MAN INSPECTION

YEARLY ESTIMATED PER PERMIT

VIOLATION	NUMBER OF PUNS	AVERAGE LENGTH OF PUNS	NUMBER DETECTED	PERIOD AVERAGE LENGTH
GRADING	1.08	12.07	1.68	23.13
REVEGETATION	0.27	27.90	0.94	42.95
DRAINAGE	0.77	6.78	0.74	27.98
WATER C.	2.98	1.00	0.38	1.00

YEARLY CLOUD-FREE SAT. PASSES = AT COST OF \$ 0.

YEARLY AIRPLANE PASSES INSPECTING MINES AT COST OF \$ 0.

YEARLY 806.0 MAN INSPECTIONS AT COST OF \$ 22890.

YEARLY SOCIAL COST OF VIOL IS \$ 489735.

TOTAL OF FINES IS \$ 61656.

TOTAL YEARLY COST IS \$ 450970.

Table 41A

ASSUMPTIONS: NO SATELLITE

7. DAYS TO AIRPLANE

7. DAYS TO MAN INSPECTION

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF PUNC	AVERAGE LENGTH OF PUNC	NUMBER DETECTED	PRIOR AVERAGE LENGTH
GRADING	1.08	11.37	12.43	23.13
REVEGETATION	0.27	25.00	6.91	42.95
DRAINAGE	0.77	4.51	3.50	27.98
WATER Q.	2.98	1.00	3.02	1.00

YEARLY CLOUD-FREE SAT. PASSES = 0.0 AT COST OF \$ 0.

YEARLY 52 AIRPLANE PASSES INSPECTING 6448.0 MINES AT COST OF \$ 115793.

YEARLY 2700.1 MAN INSPECTIONS AT COST OF \$ 76683.

YEARLY SOCIAL COST OF VIOL IS \$ 461925.

TOTAL OF FINES IS \$ 492535.

TOTAL YEARLY COST IS \$ 161866.

Table 41B

ASSUMPTIONS: NO SATELLITE
NO AIRPLANE
7. DAYS TO MAN INSPECTION

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF PUNC	AVERAGE LENGTH OF PUNC	NUMBER DETECTED	PRIOR AVERAGE LENGTH
GRADING	1.08	11.37	12.43	23.13
REVEGETATION	0.27	25.00	6.91	42.95
DRAINAGE	0.77	4.51	3.50	27.98
WATER Q.	2.98	1.00	3.02	1.00

YEARLY CLOUD-FREE SAT. PASSES = 0.0 AT COST OF \$ 0.

YEARLY 0.0 AIRPLANE PASSES INSPECTING 0.0 MINES AT COST OF \$ 0.

YEARLY 8448.0 MAN INSPECTIONS AT COST OF \$ 183123.

YEARLY SOCIAL COST OF VIOL IS \$ 461925.

TOTAL OF FINES IS \$ 492617.

TOTAL YEARLY COST IS \$ 152431.

Table 41C

ASSUMPTIONS: NO SATELLITE
7. DAYS TO AIRPLANE
14. DAYS TO MAN INSPECTION

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF RUNS	AVERAGE LENGTH OF RUNS	NUMBER DETECTED	PRIOR AVERAGE LENGTH
GRADING	1.08	12.43	6.69	23.13
REVEGETATION	0.27	22.90	3.16	42.95
DRAINAGE	0.77	4.53	1.68	27.98
WATER Q.	2.98	1.00	0.46	1.00

YEARLY CLOUD-FREE SAT. PASSES = 0.0 AT COST OF \$ 0.

YEARLY 52 AIRPLANE PASSES INSPECTING 6448.0 MINES AT COST OF \$ 115817.

YEARLY 1483.0 MAN INSPECTIONS AT COST OF \$ 42118.

YEARLY SOCIAL COST OF VIOL IS \$ 463888.

TOTAL OF FINES IS \$ 74347.

TOTAL YEARLY COST IS \$ 547476.

3. Aerial and Satellite Policies Under Adjusted 1971-74 Inspection Rates

In Section 4 of Chapter V, we have given estimates of violation frequencies and social costs when the 1971-74 inspection rate is once every 18.72 days. In this section we give tables defining the simulated costs of aerial and satellite policies under these adjusted parameters.

The seven day unit of time used in the simulations of Section 2 must be shortened. The adjusted rate of drainage control violations given none the previous week is

$$p_1 = 1.2683 \text{ per week.}$$

This is not a probability. Also, the adjusted model for water quality violations uses a duration of three days after detection. Thus, neither drainage control nor water quality violations can be simulated using a seven-day unit of time. In the simulations, to minimize the total number of simulations, a 3.5 unit of time is used.

(In retrospect, the simulations were not expensive. A unit of time of one day for all simulations would have been better. This would have avoided many technical problems as well as given more accurate comparisons with the theoretical man inspection policies of Chapter V. The simulated social costs for high inspection rates are low by thousands of dollars because detected water quality violations have durations of 3.5 days. Under one-day simulations, these durations would be significantly higher because detections would not occur on the first day of the violation. There is a continuous methodology for generating start and end times for violations which are independent of the unit of time. This methodology should be used in future cost analyses. However, the simulations which are used in this

section are sufficiently accurate to define the optimal policy within the errors made by cost and frequency estimates of the parameters involved.)

All of the simulations were run for 4000 units of time (14000 days, 2000 weeks, 38.46 years, or 0.31 year per 124 permits.) Tables 42, 47, 53, and 59 summarize the simulation results.

a. Satellite Policy Simulations

When the only detectable violations by satellite are revegetation violations, the social costs for violations under either satellite-air-man or satellite-man policies are very high. The only violation frequencies which are substantially reduced are, as expected, revegetation violations. All of the tables use a cloud-free access frequency of 0.30. (The 0.70 cloud-cover probability is a misnomer. This frequency, estimated from historical data includes not only cloud-covered accesses but any accesses to western Kentucky for which satellite data was unavailable for any reasons such as malfunctions.) Satellite-man inspections are less costly than satellite-air-man inspections. Ignoring the satellite, which in practice only influences the rate of follow-on inspections, theoretical reasons why man-only inspections are better than air-man are explained in Appendix A. When violation frequencies are high and costly, best inspection policies in order are man, air-man, satellite-man and satellite-air-man. The benefits of frequent detections outweigh the costs of inspection.

Fifty-six days is the estimated current minimal turn-around time from satellite to follow-up inspection. Misclassifications occur so frequently, however, that relatively few follow-ups are made even if the

little competition with other types of photography. While other photography may be of a high value, time is not the essence.

When airplane-man inspections and man-only inspections are compared, the total costs for man-only inspections are slightly less. This is, in fact, incorrect. An effective enforcement policy requires that permit areas where violations are detected should be inspected twice. Fines are collected only on the second or third detections. Thus, in practice, ground inspections are actually "man-man" inspections where the first inspection serves only as a pointer for the second inspection. (This is not quite true - no generalizations are true). The first man inspection, unlike air or satellite inspections, decreases social costs by starting the clock for measuring durations after detection. This discrepancy is, however, trivial.) Since airplanes cost only \$17.96 per permit and man inspections cost \$28.40, airplane-man inspections are optimal.

The optimal rate of inspection is probably less than seven days between airplane coverages. The exact optimal value can not be determined by the use of a 3.5-day simulation. Also, other factors not considered in the model, such as the interaction between start frequencies and detections, must be determined before a more accurate optimal rate is determined. Probably, a more accurate rate can not be determined except through experimentation, using varying policies on subpopulations of the mines.

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Table 42. Satellite Policy Costs

ASSUMPTIONS	INSPECTION FREQUENCY	INSPECTION COSTS SOCIAL COSTS FINES TOTAL COSTS
Revegetation violations only detected by satellite	9 days between Sat. 56 days to airplane 7 days to man	35,112 697,714 <u>1,369</u> 731,457
No airplane misclassifications	9 days between Sat. No airplane 56 days to man	25,478 712,336 <u>4,125</u> 733,689
Man inspections cost 28.40		
Airplane inspections cost 739.25 + 12n per flight	9 days between Sat. No airplane 7 days to man	26,094 699,938 <u>4,107</u> 721,925
Satellites Cost \$2000 per pass		
Social costs defined by option 6	9 days between Sat. 7 days to airplane 4 days to man	35,884 699,938 <u>4,107</u> 731,715

Table 43.

Simulations for 3.5 Day Periods With Adjusted Parameters

ASSUMPTIONS: 9. DAYS BETWEEN CAT. PASSES
56. DAYS TO AIRPLANE
7. DAYS TO MAN INSPECTION

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF PUNC	AVERAGE LENGTH OF PUNC	NUMBER DETECTED	PPIDP AVERAGE LENGTH
GRADING	11.12	45.40	0.20	45.40
REVEGETATION	0.24	49.89	0.46	66.89
DRAINAGE	1.06	45.63	0.18	52.73
WATER D.	3.28	2.08	0.02	2.10

YEARLY CLOUD-FREE CAT. PASSES = 11.9 AT COST OF \$23556.

YEARLY 11.8 AIRPLANE PASSES INSPECTING 80.6 MINES AT COST OF \$9542.

YEARLY 70.9 MAN INSPECTIONS AT COST OF \$2014.

YEARLY SOCIAL COST OF VIOL IS \$ 697714.

TOTAL OF FINES IS \$ 1369.

TOTAL YEARLY COST IS \$ 731457.

Table 44.

Simulations for 3.5 Day Periods With Adjusted Parameters

ASSUMPTIONS: 9. DAYS BETWEEN SAT. PASSES
NO AIRPLANE
56. DAYS TO MAN INSPECTION

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF RUNS	AVERAGE LENGTH OF RUNS	NUMBER DETECTED	PRIOR AVERAGE LENGTH
GRADING	1.08	44.88	0.18	45.40
REVEGETATION	0.24	48.33	0.42	56.89
DRAINAGE	1.06	49.63	0.18	52.73
WATER Q.	1.06	2.08	0.08	2.10

YEARLY CLOUD-FREE SAT. PASSES = 11.9 AT COST OF \$ 23556.

YEARLY 0.0 AIRPLANE PASSES INSPECTING 0.0 MINES AT COST OF \$ 0.

YEARLY 67.7 MAN INSPECTIONS AT COST OF \$ 1922.

YEARLY SOCIAL COST OF VIOL IS \$ 712236.

TOTAL OF FINES IS \$ 4125.

TOTAL YEARLY COST IS \$ 733689.

Table 45.

Simulations for 3.5 Day Periods With Adjusted Parameters

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ASSUMPTIONS: 9. DAYS BETWEEN SAT. PASSES
NO AIRPLANE
7. DAYS TO MAN INSPECTION

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF RUNS	AVERAGE LENGTH OF RUN	NUMBER DETECTED	PERIOD AVERAGE LENGTH
GRADING	1.12	44.12	0.20	45.40
REVEGETATION	0.24	36.67	0.78	66.89
DRAINAGE	1.06	48.68	0.16	52.73
WATER Q.	3.28	2.06	0.08	2.10

YEARLY CLOUD-FREE SAT. PASSES = 11.7 AT COST OF \$ 23348.

YEARLY 0.0 AIRPLANE PASSES INSPECTING 0.0 MINES AT COST OF \$ 0.

YEARLY 96.7 MAN INSPECTIONS AT COST OF \$ 2746.

YEARLY SOCIAL COST OF VIOL IS \$ 699938.

TOTAL OF FINES IS \$ 4107.

TOTAL YEARLY COST IS \$ 721925.

Table 45.

Simulations for 3.5 Day Periods With Adjusted Parameters

ASSUMPTIONS: 9. DAYS BETWEEN SAT. PASSES
NO AIRPLANE
7. DAYS TO MAN INSPECTION

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF PUNC	AVERAGE LENGTH OF PUNC	NUMBER DETECTED	PRIOR AVERAGE LENGTH
GRADING	1.12	44.12	0.20	45.40
REVEGETATION	0.24	36.67	0.78	66.89
DRAINAGE	1.06	48.68	0.16	52.73
WATER Q.	3.28	2.06	0.08	2.10

YEARLY CLOUD-FREE SAT. PASSES = 11.7 AT COST OF \$ 23348.

YEARLY 0.0 AIRPLANE PASSES INSPECTING 0.0 MINES AT COST OF \$ 0.

YEARLY 96.7 MAN INSPECTIONS AT COST OF \$ 2746.

YEARLY SOCIAL COST OF VIOL IS \$ 699938.

TOTAL OF FINES IS \$ 4107.

TOTAL YEARLY COST IS \$ 721925.

Table 46.

Simulations for 3.5 Day Periods With Adjusted Parameters

ASSUMPTIONS: 9. DAYS BETWEEN CAT. PASSES
7. DAYS TO AIRPLANE
4. DAYS TO MAN INSPECTION

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF PUNG	AVERAGE LENGTH OF PUNG	NUMBER DETECTED	PROB AVERAGE LENGTH
GRADING	1.12	44.12	0.20	45.40
REVEGETATION	0.24	36.67	0.78	66.89
DRAINAGE	0.56	48.68	0.16	52.73
WATER O.	3.28	2.06	0.08	2.10

YEARLY CLOUD-FREE CAT. PASSES = 11.7 AT COST OF \$ 23348.

YEARLY 11.7 AIRPLANE PASSES INSPECTING 96.2 MINES AT COST OF \$ 9790.

YEARLY 96.7 MAN INSPECTIONS AT COST OF \$ 2746.

YEARLY SOCIAL COST OF VIOL IS \$ 699,938.

TOTAL OF FINES IS \$ 4,107.

TOTAL YEARLY COST IS \$ 731,715.

Table 47. Airplane Policy Costs

ASSUMPTIONS	INSPECTION FREQUENCY	INSPECTION COSTS SOCIAL COSTS FINES TOTAL COSTS
No Misclassifications Airplane Costs $739.25 + 12n$ Man Inspection Cost \$28.40 Social Costs Defined by Option 6	7 days between airplanes 3.5 days to man inspection	189,066 343,738 -131,514 <u>401,290</u>
	3.5 days between airplanes 7 days to man inspection	309,098 387,808 -113,664 <u>582,243</u>
	14 days between airplanes 3.5 days to man inspection	99,569 413,150 - 92,050 <u>420,669</u>
	17.5 days between airplanes 3.5 days to man inspection	77,915 443,492 - 65,031 <u>456,376</u>
	21 days between airplanes 3.5 days to man inspection	65,342 467,472 - 53,706 <u>479,108</u>

Table 48.

Simulation for 3.5 Day Periods With Adjusted Parameters

ASSUMPTIONS: NO SATELLITE

4. DAYS TO AIRPLANE

7. DAYS TO MAN INSPECTION

YEARLY ESTIMATED PEP PERMIT

VIOLATION	NUMBER OF PUNC	AVERAGE LENGTH OF PUNC	NUMBER DETECTED	PEPDP AVERAGE LENGTH
GRADING	1.12	21.98	12.02	45.40
REVEGETATION	0.24	38.44	4.46	66.89
DRAINAGE	1.06	8.49	4.40	52.73
WATER D.	3.28	1.50	2.16	2.10

YEARLY CLOUD-FREE SAT. PASSES = 0.0 AT COST OF \$ 0.

YEARLY 104 AIRPLANE PASSES INSPECTING 12896.0 MINED AT COST OF \$231634.

YEARLY 2727.7 MAN INSPECTIONS AT COST OF \$ 77464.

YEARLY SOCIAL COST OF VIOL IS \$ 387808.

TOTAL OF FINES IS \$ 113664.

TOTAL YEARLY COST IS \$ 583,243.

Table 49.

Simulations for 3.5 Day Periods With Adjusted Parameters

ASSUMPTIONS: NO SATELLITE
7. DAYS TO AIRPLANE
4. DAYS TO MAN INSPECTION

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF PUNC	AVERAGE LENGTH OF RUNS	NUMBER DETECTED	PRIOR AVERAGE LENGTH
GRADING	1.12	21.72	12.36	45.40
REVEGETATION	0.24	38.11	4.48	66.89
DRAINAGE	1.06	8.02	4.22	52.73
WATER Q.	3.28	1.29	2.50	2.10

YEARLY CLOUD-FREE INT. PASSES = 0.0 AT COST OF \$ 0.

YEARLY 52 AIRPLANE PASSES INSPECTING 6448.0 MINES AT COST OF \$115817.

YEARLY 2579.2 MAN INSPECTIONS AT COST OF \$ 73249.

YEARLY SOCIAL COST OF VIOL IS \$ 343738.

TOTAL OF FINES IS \$ 131514.

TOTAL YEARLY COST IS \$ 401290.

Table 50.

Simulations for 3.5 Day Periods With Adjusted Parameters

ASSUMPTIONS: NO SATELLITE
14. DAYS TO AIRPLANE
4. DAYS TO MAN INSPECTION

YEARLY ESTIMATED PEP PERMIT

VIOLATION	NUMBER OF PUNS	AVERAGE LENGTH OF PUNS	NUMBER DETECTED	PRIOR AVERAGE LENGTH
GRADING	1.12	25.86	7.44	45.40
REVEGETATION	0.24	32.78	1.96	66.89
DRAINAGE	1.06	10.05	2.60	52.73
WATER Q.	3.28	1.57	1.74	2.10

YEARLY CLOUD-FREE SAT. PASSES = 0.0 AT COST OF \$ 0.

YEARLY 26.0 AIRPLANE PASSES INSPECTING 3224.0 MINE AT COST OF \$ 57908.

YEARLY 1467 MAN INSPECTIONS AT COST OF \$ 41661.

YEARLY SOCIAL COST OF VIOL IS \$ 413150.

TOTAL OF FINES IS \$ 92050.

TOTAL YEARLY COST IS \$ 420,669.

Table 51.

Simulations for 3.5 Day Periods With Adjusted Parameters

ASSUMPTIONS: NO SATELLITE
18. DAYS TO AIRPLANE
4. DAYS TO MAN INSPECTION

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF RUNS	AVERAGE LENGTH OF RUNS	NUMBER DETECTED	PRIOR AVERAGE LENGTH
GRADING	1.12	22.07	4.94	45.40
REVEGETATION	0.24	31.22	1.48	66.89
DRAINAGE	1.06	10.98	2.44	52.73
WATER Q.	3.28	1.74	1.24	2.10

YEARLY CLOUD-FREE SAT. PASSES = 0.0 AT COST OF \$ 0.

YEARLY 20.8 AIRPLANE PASSES INSPECTING 2579.2 MINES AT COST OF \$46327.

YEARLY 1112.2 MAN INSPECTIONS AT COST OF \$ 31588.

YEARLY SOCIAL COST OF VIOL IS \$ 443492.

TOTAL OF FINES IS \$ 65031.

TOTAL YEARLY COST IS \$ 456376.

Table 52.

Simulations for 3.5 Day Periods With Adjusted Parameters

ASSUMPTIONS: NO SATELLITE
 21. DAYS TO AIRPLANE
 4. DAYS TO MAN INSPECTION

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF PUNC	AVERAGE LENGTH OF PUNC	NUMBER DETECTED	PROPR AVERAGE LENGTH
GRADING	1.12	23.09	12.20	45.40
REVEGETATION	0.24	39.67	4.42	66.89
DRAINAGE	1.06	11.39	4.16	52.73
WATER Q.	3.28	1.83	2.56	2.10

YEARLY CLOUD-FREE SAT. PASSES = 0.0 AT COST OF \$ 0.

YEARLY 17.33 AIRPLANE PASSES INSPECTING 2149.3 MINES AT COST OF \$ 38606.

YEARLY 941.4 MAN INSPECTIONS AT COST OF \$ 26736.

YEARLY SOCIAL COST OF VIOL IS \$ 467472.

TOTAL OF FINES IS \$ 53706.

TOTAL YEARLY COST IS \$ 479108.

Table 53. Satellite Policy Costs
If No Misclassifications

ASSUMPTIONS	INSPECTION FREQUENCY	INSPECTION COSTS SOCIAL COSTS FINES TOTAL COSTS
All violations correctly classified Man inspections cost 28.40 Airplane Inspections cost 739.25 + 12n Satellites Cost \$2000 per lass Social Costs Defined by Option 6	9 days between Sat. 56 days to airplane 7 days to man	47,918 552,868 - 11,278 <u>589,508</u>
	9 days between Sat 56 days to airplane 4 days to man	45,480 526,386 - 24,784 <u>547,082</u>
	9 days between Sat. No airplane 56 days to man	34,422 563,206 - 8,403 <u>589,225</u>
	9 days between Sat. 7 days to airplane 4 days to man	63,120 480,840 39,804 <u>504,155</u>
	9 days between Sat. No airplane 7 days to man	42,402 505,930 25,155 <u>523,176</u>

Table 54.

Simulations for 3.5 Day Periods With Adjusted Parameters

ASSUMPTIONS: 9. DAYS BETWEEN SAT. PASSES
56. DAYS TO AIRPLANE
7. DAYS TO MAN INSPECTION
No Satellite Misclassifications

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF PUNS	AVERAGE LENGTH OF PUNS	NUMBER DETECTED	PRDP AVERAGE LENGTH
GRADING	1.12	25.91	1.08	45.40
REVEGETATION	0.24	36.56	0.38	66.89
DRAINAGE	1.06	20.17	0.98	52.73
WATER D.	3.28	2.06	0.22	2.10

YEARLY CLOUD-FREE SAT. PASSES = 12.2 AT COST OF \$ 24440.

YEARLY 12.2 AIRPLANE PASSES INSPECTING 509.4 MINES AT COST OF \$15146.

YEARLY 293.4 MAN INSPECTIONS AT COST OF \$8332.

YEARLY SOCIAL COST OF VIOL IS \$ 552,868.

TOTAL OF FINES IS \$ 11,278.

TOTAL YEARLY COST IS \$ 589,508..

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Table 55.

Simulations for 3.5 Day Periods With Adjusted Parameters

ASSUMPTIONS: 9. DAYS BETWEEN CAT. PASSES
56. DAYS TO AIRPLANE
4. DAYS TO MAN INSPECTION
No satellite misclassifications

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF PUNS	AVERAGE LENGTH OF PUN	NUMBER DETECTED	PRIOR AVERAGE LENGTH
GRADING	1.12	28.65	1.50	45.40
REVEGETATION	0.24	33.33	0.40	66.69
DRAINAGE	1.06	17.07	0.88	52.73
WATER Q.	3.28	1.97	0.48	2.10

YEARLY CLOUD-FREE CAT. PASSES = 11.8 AT COST OF \$ 23556.

YEARLY 11.8 AIRPLANE PASSES INSPECTING 422.4 MINES AT COST OF \$ 13776.

YEARLY 286.9 MAN INSPECTIONS AT COST OF \$ 8148.

YEARLY SOCIAL COST OF VIOL IS \$ 526386.

TOTAL OF FINES IS \$ 24784.

TOTAL YEARLY COST IS \$ 547082.

Table 56.

Simulations for 3.5 Day Periods With Adjusted Parameters

ASSUMPTIONS: 9. DAYS BETWEEN SAT. PASSES
NO AIRPLANE
56. DAYS TO MAN INSPECTION
No Satellite Misclassifications

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF PUNS	AVERAGE LENGTH OF PUNS	NUMBER DETECTED	PROB AVERAGE LENGTH
GRADING	1.12	25.42	1.26	45.40
REVEGETATION	0.24	47.56	0.48	66.89
DRAINAGE	1.06	22.00	0.98	52.73
WATER Q.	3.28	2.06	0.16	2.10

YEARLY CLOUD-FREE SAT. PASSES = 12.0 AT COST OF \$24076.

YEARLY 0.0 AIRPLANE PASSES INSPECTING 0.0 MINES AT COST OF \$ 0.

YEARLY 364.3 MAN INSPECTIONS AT COST OF \$ 10346.

YEARLY SOCIAL COST OF VIOL IS \$ 563206.

TOTAL OF FINES IS \$ 8403.

TOTAL YEARLY COST IS \$ 589225.

Table 57.

Simulations for 3.5 Day Periods With Adjusted Parameters

ASSUMPTIONS: 9. DAYS BETWEEN SAT. PASSES
7. DAYS TO AIRPLANE
4. DAYS TO MAN INSPECTION
No Satellite Misclassifications

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF PUNS	AVERAGE LENGTH OF PUNS	NUMBER DETECTED	PRIOR AVERAGE LENGTH
GRADING	1.12	21.40	2.72	45.40
REVEGETATION	0.24	37.00	1.22	68.89
DRAINAGE	1.06	11.68	1.66	52.73
WATER O.	3.28	1.90	0.76	2.10

YEARLY CLOUD-FREE SAT. PASSES = 11.8 AT COST OF \$ 23660.

YEARLY 11.8 AIRPLANE PASSES INSPECTING 980.0 MINES AT COST OF \$ 20506

YEARLY 667.4 MAN INSPECTIONS AT COST OF \$ 18954.

YEARLY SOCIAL COST OF VIOL IS \$ 480840.

TOTAL OF FINES IS \$ 39804.

TOTAL YEARLY COST IS \$ 504155.

Table 58.

Simulations for 3.5 Day Periods With Adjusted Parameters

ASSUMPTIONS: 9. DAYS BETWEEN SAT. PASSES
 NO AIRPLANE
 7. DAYS TO MAN INSPECTION
 No Satellite Misclassifications

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF PUNS	AVERAGE LENGTH OF PUNS	NUMBER DETECTED	PERIOD AVERAGE LENGTH
GRADING	1.12	26.63	3.18	45.40
REVEGETATION	0.24	28.33	0.90	66.89
DRAINAGE	1.06	13.27	1.58	52.73
WATER C.	3.28	1.97	0.48	2.10

YEARLY CLOUD-FREE SAT. PASSES = 11.9 AT COST OF \$23816.

YEARLY 0.0 AIRPLANE PASSES INSPECTING 0.0 MINES AT COST OF \$ 0.

YEARLY 654.4 MAN INSPECTIONS AT COST OF \$ 18586.

YEARLY SOCIAL COST OF VIOL IS \$ 505930.

TOTAL OF FINES IS \$ 25155.

TOTAL YEARLY COST IS \$ 523176.

Table 59. Ground Inspection Simulated Costs

ASSUMPTIONS	INSPECTION FREQUENCY	INSPECTION COSTS SOCIAL COSTS FINES TOTAL COSTS
All violations correctly classified Man Inspections Cost \$28.40 Social Costs Defined by Option 6	Every 7 days	183,124 343,124 -130,036 <u>396,826</u>
	Every 17.5 days	73,250 443,492 - 65,178 <u>451,564</u>

Table 60.

Simulations for 3.5 Day Periods With Adjusted Parameters

ASSUMPTIONS: NO SATELLITE
NO AIRPLANE
7. DAYS TO MAN INSPECTION

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF RUNS	AVERAGE LENGTH OF RUNS	NUMBER DETECTED	PROB AVERAGE LENGTH
GRADING	1.12	21.72	12.20	45.40
REVEGETATION	0.24	38.11	4.42	56.89
DRAINAGE	1.06	8.02	4.16	52.73
WATER Q.	3.28	1.29	2.56	2.10

YEARLY CLOUD-FREE SAT. PASSES = 0.0 AT COST OF \$ 0.

YEARLY 0.0 AIRPLANE PASSES INSPECTING 0.0 MINES AT COST OF \$

YEARLY 6448.0 MAN INSPECTIONS AT COST OF \$ 183124.

YEARLY SOCIAL COST OF VIOL IS \$ 343738.

TOTAL OF FINES IS \$ 130036.

TOTAL YEARLY COST IS \$ 396826.

Table 61.

Simulations for 3.5 Day Periods with Adjusted Parameters

ASSUMPTIONS: NO SATELLITE
 NO AIRPLANE
 18. DAYS TO MAN INSPECTION

YEARLY ESTIMATES PER PERMIT

VIOLATION	NUMBER OF PUNIS	AVERAGE LENGTH OF PUNIS	NUMBER DETECTED	PRIOR AVERAGE LENGTH
GRADING	1.12	22.07	4.96	45.40
REVEGETATION	0.24	31.22	1.48	66.89
DRAINAGE	1.06	10.98	2.44	52.73
WATER Q.	3.28	1.74	1.24	2.10

YEARLY CLOUD-FREE SAT. PASSES = 0.0 AT COST OF \$ 0.

YEARLY 0.0 AIRPLANE PASSES INSPECTING 0.0 MINES AT COST OF \$ 0.

YEARLY 2579.2 MAN INSPECTIONS AT COST OF \$ 73250.

YEARLY SOCIAL COST OF VIOL IS \$ 443492.

TOTAL OF FINES IS \$ 65178.

TOTAL YEARLY COST IS \$ 451564.

4. Future Satellite and Computer Technology

Of the four (4) violation categories considered in this report, only revegetation can be treated adequately by a routine application of data as it is now available in the Landsat program. At this point, spectral resolution does not appear to be a critical factor. The major difficulties encountered were:

- inability to observe the ground on a frequent and routine basis (due primarily to cloud cover);
- inadequate spatial resolution;
- delays in obtaining Landsat imagery.

As indicated in Section VI.3.a., good quality, 70% cloud-free, satellite imagery of the ground in the western Kentucky coal field is obtained in only about 30% of the satellite accesses to the area. For a given satellite an 18-day return frequency would result in about six (6) successful accesses per year, an average reinspection time of about two (2) months. This time can be reduced to approximately one month by including imagery from both Landsat-1 and Landsat-2. Although the strategy of using the cloud-free portions of all Landsat-imagery has not been tested, in principle the approach should yield an average reaccess period of less than one month, but greater than nine (9) days. Thus, with the existing satellites, an effective reinspection rate limit of perhaps once every 18 days might be obtained by classifying all useable Landsat imagery for the west Kentucky coal field. Under this approach, some of the imagery would not be purchased because of poor image quality or because of 100% cloud cover, thus the cost would not quite be twice that of a straight 18 day satellite coverage. Some additional savings might be realized by reference to

NOAA-weather satellite data as an aid in selecting useable Landsat-data. Further reduction in the time between inspections might be obtained if radar were included on some future Landsat. Since radar is not affected by clouds, fog, haze, snow cover or nighttime, a considerable increase in the rate and the reliability of reinspection could be expected.

In the Western Kentucky coal field, the principle method of mining is by area stripping. To be considered current, grading and backfilling must not be more than two spoil ridges behind the pit being worked. The width of a given spoil ridge depends on characteristics of the mine operation; however, a subjective estimate based on observing a limited number of mines suggests a width of about 33 meters. On that basis, to detect grading violations it is necessary to recognize the width of three, 33-meter spoil ridges to within one ridge width. This resolution may approximate an upper bound to the detection of water quality, drainage plan, and wildcat strip mining violations.

Spoil ridges usually are linear elements, extending for much greater lengths than their widths. If an extended region of $k \times n$, with $k \ll n$, pixels for a spoil ridge is observed on a recognition map, misclassification errors of boundary pixels might limit the detected width of $k \pm 1$ pixels. Thus the successful detection of a grading violation requires a pixel width of about 33 meters. This is approximately one half the present Landsat pixel size. An increase of resolving power by a factor of 2 would give 4 times as much data and 4 times as much square footage of recognition maps (unless line printer symbols could be reduced or some alternative graphic device were used). The above resolution of 33 meter pixel widths or less is a possibility in the near future. Black and white imagery from the return beam video sensors of Landsat-C will come close to this size and may prove to be adequate for most violations

except for those involving water quality. This would reduce misclassification costs and could prove to be cost effective if the elapsed time between satellite coverage and ground inspection were reduced to a week or less.

The other important cost considerations are inspection costs -- the computer plus labor costs. An intriguing aspect of Landsat data is the potential for programming a computer in such a way as to reduce the costs of photointerpretation.

One advantage of computer programmed maps is that all areas which lie in a category of noninterest could be printed out as blanks. The remaining areas could hardly be missed by a photointerpreter. Lakes and rivers could be used as reference points.

In the future, cluster analysis packages could include a routine which precisely defines the coordinates of the pixels using known ground truth area. A computer could be programmed to do the interpretation, with less error than a human interpreter. In place of costly recognition maps, summary printouts of the computer photointerpretation results could be made. The computer could also be programmed to review historical tapes to pinpoint any changes which have occurred and to ignore consistent past misclassifications at specific areas.

Thus through automation, many costs connected to photointerpretation could be dropped. The dominant cost, however, is in the computer cluster analysis routines to recognize ground truth. Recent research has shown that such routines may not be necessary. Satellite data have been used, (26) and (27), successfully over a span of two years to classify and map surface mined areas and to measure the successfulness of reclamation practices without use of repetitive cluster analysis routines.

Cluster analysis routines using ground-truth routines are necessary because the categories of channel voltages corresponding to ground-truth categories change with each new satellite pass. The biggest fluctuations are due to seasonal reflectance properties. If all voltages within a single season are assumed to change by a random constant plus a random scale factor for each channel, simple linear adjustments can be used each year for recognition mapping after the initial decision rules have been obtained once and for all each season.

The process used in (27) was very simple, probably very inexpensive, and apparently very accurate to within the limits of the pixels. Band-ratioed data and linear regression analysis were used to extend Landsat signature analysis of September 1972 to two further analyses of September 1973 and July 1974.

In (27), misclassification did occur in the analysis. For example, the town of Keyser, Maryland was classified as a strip mine. Another false alarm was a railroad yard.

In (27), eight mines were selected to estimate the accuracy of area measurements from Landsat data. While the accuracy was found to average 7%, the following must be noted:

- Landsat data was trained for the 1972 data. The sum of residual errors was constrained to be zero -- clearly minimizing the average possible error. If the data were extended to untrained areas -- the errors could be expected to be larger.
- Landsat errors for 1974 were 12%, with five of the seven areas underestimated. While the claim is made that the

underestimation is "due to natural revegetation around the edges of the mine" and overestimation due to "increased mining area," it is conceivable that the large errors are simply "proof" that trained signatures lose precision both spatially and temporally.

- The eight mine areas were large, ranging from 31.4 acres to 243.8 acres. Misclassified pixels occur on the boundaries between different area categories. For large areas, a smaller percentage of the pixels lie on the boundary, thus giving lower misclassification errors. Indeed, the residuals in (27) were as large for the small mines as for the large mines.

The problems encountered in misclassification errors in (26) and (27) were similar to those observed in Madisonville. The misclassifications are probably due more to resolution than to the decision rules. If resolution can be decreased in the future, it is important that simple procedures such as (27) do exist for extending signatures temporally and thus reducing costs.

VII. CONCLUSIONS AND RECOMMENDATIONS

1. Introduction

The goal of this project was to estimate the costs and benefits of using satellite or airplane photography for the inspection of surface coal mining violations in western Kentucky. New inspection processes are cost effective if either the net increase in inspection costs is exceeded by the benefits in reduced social costs of mine violations and increased fines or if the net decrease in inspection costs exceeds any increase in social costs and decrease in fines.

The alternative policies considered in this report were satellite-air-man, satellite-man, air-man, and man only inspection policies. In each of these policies, satellites and airplanes serve only as a pointer for follow-up inspections. The benefits of detection of surface coal mining violations are assumed to occur only when a ground inspection is made.

The cost of an inspection policy has several components. We first summarize the inspection costs. Airplane color IR photography of n active coal mines in western Kentucky costs approximately $\$739 + \$12n$. This estimate applies when only active coal mines are photographed. In this case, only one roll of film is required to photograph all of the estimated 124 permit areas which cover a total of less than twenty square miles. If the entire coal mining region including farms and towns lying in the area were photographed, an estimated area of 4300 square miles requiring nine rolls of film at a total cost of \$6,110 would be required.

Estimates of the costs of satellite photography and interpretation

are less accurate than those for airplane inspection. Total costs depend on the elaborateness of the computer decision rules for interpreting the data and on the computer itself. Since the computer would be state-owned, the costs would probably be less than the use of time-sharing facilities. Our estimate of a satellite inspection of the entire active coal mining area in western Kentucky is \$2,000.

A lower bound for the cost of manned inspection is \$28.40 per permit area. This gives a total cost of \$3,522 to inspect the estimated 124 permit areas. The figure of \$28.40 may be low. This estimate was made by assuming ten inspectors make 400 inspections per month. During 1971-74, about 207 inspections were made per month. (An average of only 57.5 inspection reports were filed each month. See Section 4, Chapter V for an explanation of the adjusted estimate of 207 inspections per month. Inspection reports are now required to be written for each inspection. Because this is an extra burden on the inspector, future inspection rates could be less than the 207 inspections per month per ten inspectors.) At 207 inspections per month per ten inspectors, the cost is \$46.72. We have used the values \$28.40 and \$50 as two alternatives in our study.

A means of reducing the costs of manned inspections is to inspect only those mines where violations are occurring. This is the basis for analyzing policies where satellites or airplanes serve as pointers.

Although satellites and/or airplanes cost less than manned inspections, they are sufficiently expensive to require a study to determine if they are beneficial. They are cost-effective under the following conditions:

- Misclassification probabilities are not large. That is, violations are detectable.
- The elapsed follow-up time after either a satellite or airplane detection is not large. That is, the social costs accrued by violations during the elapsed time are small relative to the total social costs during the period which they exist.
- Violations do not start frequently.

All of the above refer to the efficiency of the satellite or airplane to serve as a pointer. Thus, to be efficient, the pointer must detect violations and manned inspections must be made in a sufficiently short period of time. Furthermore, the pointer is not efficient if it is known a priori that a violation is occurring with high probability.

While this study is for satellite and aircraft inspection policies, we begin by examining the frequency and costs of violations at the surface coal mines because these parameters are required in the cost effectiveness study.

2. Social Costs and Frequencies of Violations

Our first task for this project was to categorize surface mining violations and estimate their costs and frequencies using inspection data for the period 1971-74. There is at present insufficient data to obtain accurate estimates of the social costs of coal mining violations. Our method of estimation was to scale up scores assigned by the ten inspectors from western Kentucky to each of the violations. The scale factor was determined by using a figure of \$50 per acre per year for revegetation violations. Costs per week were then determined by dividing the estimated total costs by the average duration of a violation.

The only social cost estimate which is not entirely subjective is the estimated cost of revegetation violations (\$24.04 per week). A sensitivity analysis was made by varying the other three violation costs. The costs were varied by using three different average durations. These durations were: (1) best estimated duration, (2) longest possible duration as restricted by the one-year permit renewal and bond release regulations, and (3) shortest possible duration when inspections are made daily.

The conclusions about the cost effectiveness of various inspection policies depend on the amount which inspection policies reduce the social costs. If a social cost cannot be reduced, then the value of the social cost is irrelevant. For example, it is not known with certainty that detections of water quality violations have any effect on water quality violation duration or frequency. If there is no shortening effect, then the only benefits of detection of these violations are fines.

The total amount of fines collected for water quality violations in 1974 was approximately \$60,000. If, as our original estimates showed, inspections were made only once per 55 days, then at a daily inspection rate, the total collected fines per year would grow to over \$1,000,000, assuming water quality violations did not decrease. Inspectors believe that the figure of \$1,000,000 for fines is far too high. Indeed, indications from the increased inspection rate of 1975 are that the total amount of fines collected per year remains constant independent of the increased detection rate.

If the total amount of fines remains constant, and if the duration and frequency of water quality violations remain constant, then clearly there

is no benefit in the detection of water quality violations. If this is the case, then airplane and satellite policies can be very cost-effective. The other three violation types (drainage control, revegetation, and grading) last for longer periods of time and their social costs per week are lower. The longer lengths increase the maximum elapsed time between satellite or airplane inspections and follow-up manned inspections which can occur to have a cost effective inspection policy. Also, it would not be necessary to correctly classify water quality violations.

That there will be no future benefits in detecting water quality violations is not expected. It is assumed that there will be a benefit. The benefit could be from either fines or a decreased duration after detection. Two complete analyses were made under two different assumptions.

Case 1. Inspections during 1971-74 were once every 55 days.

Inspection reports were filed during 1971-74 at a rate of once per 55 days per permit area. It was assumed that a constant rate of fines per detection of water quality violations would be levied independent of the inspection rate. Under this assumption, total fines for a year at the daily inspection rate would be \$520,232 if water quality violations last seven days and \$1,133,874 if water quality violations last three days. The total cost of water quality violations per year was estimated to be between \$691,916 and \$1,384,173 depending on the social cost option. Although the maximum estimated total of fines collected under these assumptions would be less than the social costs of water quality violations, inspectors concluded these estimates were too high. A second analysis using "adjusted" parameters was called for.

Case 2. Inspections during 1971-74 were once every 18 days.

The number of inspection reports filed is less than the total number of inspections during 1971-74. This causes ambiguity in the estimates for rates of violations, detections, and fines. We have made the assumption that all inspections whether reported or not, have identical characteristics. This implies that the decision to not report or to report is made independently of violations. Serious violations therefore have odds of $(55-18) \div 18$ of not being reported. Case 1 assumes that inspections which are not reported count as no inspection.

Many more detections are occurring under Case 2 than under Case 1. This has two effects on the estimated violation parameters:

- The overall frequency of violations is the same in both cases. However, in Case 2, the estimated average length is shorter and the frequency of starts is higher.
- The overall rate of fines per year is the same in both cases. That is, twelve fines averaging \$500 each were collected each year. However, in Case 2, the estimated rate of fines per detection of water quality violations is lower because the detection rate is increased.

In Case 2, it is assumed that water quality violations last an average of seven days under no inspections and an average of three days under daily inspection. The decrease in the benefits of fines per detection is, therefore, offset by the benefit of a decrease in duration.

The conclusions of the next section are based on Case 2 assumptions and social costs defined in the table below. Conclusions for Case 1 and for other cost options can be found in the previous chapters.

Table 62. Violation Parameters

Violation	Frequency of Starts Per Year	Average Duration Under No Inspection (Weeks)	Average Duration Under Daily Inspection (Weeks)	Social Cost Per Week
Grading	1.544	26.00	13.00	\$ 26.64
Revegetation	0.376	34.67	17.33	\$ 24.04
Drainage Control	1.940	26.00	4.00	\$ 60.67
Water Quality	0.489	1.00	0.50	\$997.73

3. Cost/Benefit Analysis

Two methods of analysis were used. For ground inspection analysis exact mathematical formulae were derived. These were used to obtain exact optimal inspection rates and costs. (Exact only within the model used and the values of the parameters. The model and the values are, of course, only ideal and do not represent exact real-world conditions.)

Computer simulations were used to analyze satellite and airplane policies. A shortcoming of these simulations was caused by the extreme differences among the durations of the violation types. For reliable simulations, it was necessary to simulate random combinations of all four violation types. Discrete blocks of time were used. Within each block, random number generators determine all of the conditions present at that time. As the length of the time unit is decreased, the number of simulations must be increased in order to adequately simulate drainage control, revegetation, and grading

violations. The unit of time must be no greater than the 3.5 day average duration of water quality violations after they are detected. This unit was used.

The 3.5 day unit set limitations on the results. For example, detected water quality violations last exactly 3.5 days in the simulation. In reality, and under our mathematical formula, the average duration is closer to seven days under low inspection rates because water quality violations would not be observed on the first day. Also, when inspection rates are once per 3.5 days, all water quality violations are detected in the simulation. In practice, some water quality violations endure for less than 3.5 days and would not be observed.

Thus, there is a discrepancy between the simulation and formulae for man only inspections. At high inspection rates, fines are higher and social costs are less under simulations than under the formulae. Thus, for comparisons of costs, the satellite and airplane policy costs are compared only with the simulated manned inspection costs and not with the theoretically estimated costs.

Table 63 lists the costs of those inspection policies which were simulated. Costs when manned inspections are \$50 were not given earlier in this report but are simply derived from calculations using the number of inspections listed in the previous tables. These costs are given in Table 64.

Before summarizing the table, some explanations are necessary. In the simulation, a decision had to be made as to whether or not a violation occurring in a 3.5 day unit of time which was detected by satellite would result in a follow-up detection if the elapsed time were 3.5 days. The choice

Table 63. Summary of Inspection Policy Costs
Ground Inspection Costs \$28,40

Assumptions	Inspection Policy Lag Times			Costs			
	Satellite	Airplane	Ground	Inspection	Social	Fines	Total
Revegetation violation only detectable by satellite	9 days	56 days	7 days	35,112	697,714	1,369	731,457
	9 days	NO AIR	56 days	25,478	712,336	4,125	733,689
	9 days	NO AIR	7 days	26,094	699,938	4,107	721,925
	9 days	7 days	3.5 days	35,884	699,938	4,107	731,715
	9 days	NO AIR	3.5 days				
No Misclassification	9 days	56 days	7 days	47,918	552,868	11,278	589,508
	9 days	56 days	3.5 days	45,480	526,386	24,784	547,082
	9 days	NO AIR	56 days	34,422	563,206	8,403	589,225
	9 days	7 days	3.5 days	63,126	480,840	39,804	504,155
	9 days	NO AIR	7 days	42,402	505,930	25,155	523,176
Airplane Policies	No Sat.	7 days	3.5 days	189,066	343,738	131,514	401,290
	No Sat.	14 days	3.5 days	99,569	413,150	92,050	420,669
	No Sat.	17.5 days	3.5 days	77,915	443,492	65,031	456,376
	No Sat.	21 days	3.5 days	65,342	467,472	53,706	479,108
	No Sat.	3.5 days	7 days	309,098	387,808	113,664	582,243
Ground Inspection Only	No Sat.	NO AIR	7 days	183,124	343,124	130,036	396,826
	No Sat.	NO AIR	17.5 days (1974 rate)	73,250	443,492	65,172	451,564

was that it would be. Thus, a 3.5 day follow-up inspection lag is identical to no lag. Similarly, a seven day lag represents a lag greater than 3.5 and less than seven. Under zero misclassification probabilities all satellite detections are detected in the follow-up if the lag is 3.5 days.

In the tables, in some cases when the follow-up lag after a satellite is held constant, s-a-m policies are better than s-m policies and in other cases the reverse is true. These cases are neither due to random errors nor errors in the computer program. A complete justification for the ordering of the costs has no effect on our conclusions. However, the ordering is explained by the following:

- Airplane costs include fixed as well as per unit costs. When very few follow-up inspections are required, airplanes are less cost effective. This occurs when only revegetation violations are detected by satellite.
- When several follow-up inspections are required, the effectiveness of airplanes depends on the number of satellite detections which result in follow-up detections. S-a-m is optimal when no satellite misclassifications occur (high follow-up rate), the follow-up lag is at least seven days (several areas have water quality violations ending with no new ones starting), and the lag between airplane and ground inspection is 3.5 days (the airplane selects precisely those violations which still exist.)

It is clear from the tables that satellite policies are not cost effective. There are several reasons.

- The frequency of satellite coverage is limited by the orbital path, the period of revolution, and the frequency of cloud-cover.
- The satellite costs of inspection are approximately equal to low-altitude airplane costs.
- At present, there is an approximate two-month minimum lag between satellite inspection and follow-up inspection.
- At present, the resolution is too low to detect violations other than revegetation violations.
- At present, water quality violations are of short duration, occur frequently, and have high social costs.

Under the assumption of no misclassifications and no elapsed time between airplane and manned inspections airplane-man inspection is definitely optimal. This is not indicated by Table 63. The explanation of our conclusion is made clear, however, by pointing out other shortcomings of our model.

We have assumed that a follow-up ground inspection is made after every violation detection. In practice, this is not necessary. It is known that a revegetation violation cannot be corrected until the next seeding season. A grading violation, once detected by a ground inspector, lasts an average of three months independently of the total number of inspections made. Thus permit areas having only these violations need not be inspected every week. A one-to-one follow-up inspection need be made only for water quality and possibly drainage control violations. Thus, the costs of airplane-man inspections can be considerably reduced with no increase in social costs. The optimal rate of airplane inspections is therefore, under our assumptions, less

Table 64. Summary of Inspection Policy Costs
Ground Inspections Costs \$50.00

Assumptions	Inspection Policy Lag Times			Costs			
	Satellite	Airplane	Ground	Inspection	Social	Fines	Total
Revegetation violation only detectable by satellite	9 days	56 days	7 days	36,644	697,714	1,369	732,989
	9 days	NO AIR	56 days	26,940	712,336	4,125	735,151
	9 days	NO AIR	7 days	28,183	699,938	4,107	724,014
	9 days	7 days	3.5 days	37,973	699,938	4,107	733,804
No Misclassification	9 days	56 days	7 days	54,255	552,868	11,278	595,845
	9 days	56 days	3.5 days	51,677	526,386	24,784	553,279
	9 days	NO AIR	56 days	42,291	563,206	8,403	597,094
	9 days	7 days	3.5 days	77,952	480,840	39,804	518,788
	9 days	NO AIR	7 days	56,537	505,930	25,155	537,311
Airplane Policies	No Sat.	7 days	3.5 days	244,777	343,738	131,514	457,001
	No Sat.	14 days	3.5 days	131,256	413,150	92,050	452,356
	No Sat.	17.5 days	3.5 days	101,939	443,492	65,031	480,400
	No Sat.	21 days	3.5 days	85,676	467,472	53,706	499,442
	No Sat.	3.5 days	7 days	368,016	387,808	113,664	641,161
Ground Inspection Only	No Sat.	NO AIR	7 days	322,401	343,124	130,036	536,103
	No Sat.	NO AIR	17.5 days	128,961	443,492	65,172	507,275

than seven days.

If, however, the elapsed time between airplane and ground inspection is greater than 3.5 days, then our model indicates that ground inspection is optimal.

Under the parameters listed in Table 62, the optimal number of inspectors, which minimizes manned inspection only costs, is ten. This value is independent of inspection costs over the range of \$28.40 to \$50.00 per inspection. This invariance under inspection costs occurs because, for a fixed number of inspectors, the inspection costs are proportional to the average number of days between inspection. At \$28.40, ten inspectors make 400 inspections per month or one inspection per permit each 9.4 days. At \$50.00, ten inspectors make 207 inspections per month or one inspection every 18 days. The optimal rate of inspection, from mathematical formulae, are approximately once every 9.5 days if inspections cost \$28.40 and once every 18 days if inspections cost \$50.00.

The fact that the optimal inspection rate is equal to the estimated 1971-74 rate is fortuitous. This result is consistent with a definition of costs (or utility) which assumes rational people choose policies which maximize a utility function. Thus, we might have adjusted the social cost estimates in such a manner that the 1971-74 inspection rates were optimal. Fortunately, this is unnecessary.

The optimal number of inspectors is proportional to the number of permits. Since ten inspectors should inspect 124 permit areas, an additional inspector should be hired for every additional 12 permits.

If inspections cost \$28.40, recommended policy is air-man with

airplane inspections once per week and follow-up manned inspections within three days. From Table 49, this implies that 2579 manned inspections will be made per year. As we have already explained, this number can be decreased. If an inspector makes 480 ground inspections per year, then at most five inspectors are required.

If inspections cost \$50.00, then an air-man policy with airplane inspections on a biweekly basis and follow-up manned inspections within three days is approximately optimal. From Table 50, this implies that 1467 manned inspections will be made per year. If each inspector makes 250 inspections per year, then six inspectors are required.

There are other benefits of satellite and airplane inspections which have not yet been considered. These are discussed in the next section.

4. Recommendations for Future Analysis

The fundamental result of our study is that water quality violations are a problem in western Kentucky. Other conclusions rest on a less firm foundation. Our estimates of the social costs of water quality violations are purely subjective. Better estimates of these costs should be made. Unfortunately, this requires a rigorous study beyond the limits of the time and cost constraints for this project.

The occurrence of water quality violations may be very different from that assumed in our model. They probably do not occur randomly. Since the source of these violations is due either to ground water or surface runoff, the violations could be highly correlated with specific permit areas or with

rainfall conditions. If problem areas can be pinpointed, then these violations can be detected with high efficiency without high inspection rates.

Our ground truth data did not include water quality. The ability to classify water quality violations by low altitude color IR is therefore unknown.

We recommend that water quality violations be studied more thoroughly. Better estimates of the social costs should be made. An analysis using ground truth data together with color IR should be made to estimate airplane misclassification probabilities.

But more important, a study of enforcement policies should be conducted. Better means of controlling water quality should be researched. If mine operators continue to violate water quality standards in the presence of high penalties, then the control of water quality must either be expensive or impossible.

Theoretically, there is an optimal rate for fining violations or suspending operations. The optimal inspection policy and optimal penalty rate should be solved simultaneously. The solution depends on an unknown. This is the behavior of violation frequencies under varying enforcement policies. This can be modelled as a two-person game.

The opinion of some inspectors is that the present penalties are so low that increased inspection rates will not decrease the frequency of starts of new violations. (This was, in fact, the assumption used in our cost/benefit study.) This suggests that fines should be increased. It is possible that the costly water quality violations would disappear under an optimal average fine. If this were the case, then inspection rates could be substantially decreased and satellites would be more effective.

If water quality violations can be eliminated, the second most costly violation is drainage control. Such violations start when mining is shifted to a different drainage area. The area in which mining is being conducted is observable from satellite. The geometry of the sedimentation pond and drainage area is observable in airplane photography. Precise measurements of the turbidity of the influent and effluent from the sedimentation pond are feasible by ground inspection. The question of whether color IR is sufficiently precise for measuring sediment yield is also unknown. A ground truth study of color IR should be conducted to answer this question. At present, airplane photography is definitely better than satellite photography in all aspects of physical and chemical water quality measurements or predictions. The study in [20] seems to indicate that observations on the geometry of sedimentation pond (i. e. dimensions and sideslope properties) are sufficient for the detection of inadequate sedimentation ponds.

Grading violations are easily detectable by airplane photography and, with better resolution (see Chapter VI) by satellite. Revegetation violations are detectable by either satellite or airplane. The most serious violation occurs when mined areas end up as orphan land. The Commonwealth must then bear the burden of rehabilitation. Our assumption is that either this does not occur (all grading and revegetation violations end within a year) or that the forfeiture of bonds covers this additional expense. There are two possibilities when this need not be the case:

- Wildcat strip mining
- Corrupt mine inspectors

Hopefully, the second case does not occur. Throughout this report we have

assumed an ideal case of perfect ground inspections with no errors (on which our estimates of violation frequencies are based). There is a probability that an error may be made which simultaneously results in a bond release and orphan land. Reference (4) makes allegations that support this point of view. Satellite photography on a semiannual basis could be used to verify that land is graded (under a presumed future improved resolution) and revegetation is taking place. If semiannual inspections prevent one or more permitted areas from becoming unrehabilitated orphan land, the inspections are exceedingly cost effective.

The question of whether wildcat strip mining is either prevalent or serious in Western Kentucky is debatable. During the past several years, according to communications with inspectors, only two wildcat strip mines have been detected in Western Kentucky. The present frequency of strip mining without a permit is unknown because the entire active coal mining area of 4300 square miles is not inspected as a whole.

It is believed that if any wildcat strip mining exists in western Kentucky, it is well camouflaged. Apparently, not only is the mining area graded and revegetated, but so are the roads leading to the mining area. Thus, wildcat strip mining social costs may be trivial (if so, perhaps wildcatting should be ignored when detected to minimize costs!). Satellites cannot be used effectively to detect wildcat strip mining under present resolution. Airplane costs for coverage of the entire 4300 square mile active coal mining area are probably too large. No accurate assessment of the benefits of complete airplane coverage or future satellite coverage can be made without experimentation.

Finally, the total benefit of satellite inspection of coal mines depends on how much of the inspection costs can be outlayed to other benefits not related to strip mining. Besides coal mining inspections, satellite photography can be used in Kentucky for other purposes such as forestry, land use, and agriculture. The cataloguing of the amount of acreage of resources varying from tobacco crops to surface water is extremely valuable. Knowledge of crop acreage is important to farmers because of its influence on costs and profits.

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